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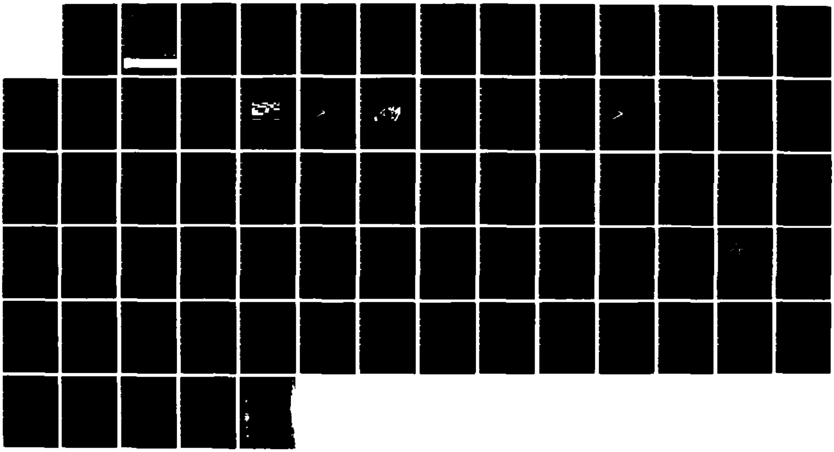

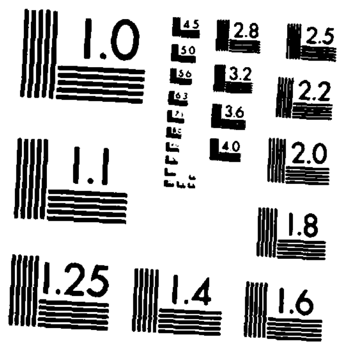

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Technical Report NAVTRAEQUIPCEN 81-C-0105-4

SIMULATOR DESIGN FEATURES FOR AIR-TO-GROUND BOMBING I. PERFORMANCE EXPERIMENT I.

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Interim Final Report for Period
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The Visual Technology Research Simulator (VTRS) at the Naval Training Equipment Center was used to study the effects of six factors on air-to-ground bombing performance. The purpose of the experiment was to obtain information relevant to the design of simulators used for skill maintenance and transition training and to obtain information for making decisions about future transfer-of-training studies. The task was 30-degree cone

pattern manual dive bombing initialized at 8000 feet altitude. Pilots who participated in the experiment were Navy fleet pilots experienced in air-to-ground bombing. Factors studied were system lag (117 msec vs. 217 msec), background offset (-40 degrees vs. no offset), edge segmentation (up to 16 per modelled edge vs. no-edge segmentation), motion (platform motion vs. none), and g-seat (operational g-seat vs. none). Scene type was also included as a factor with four scenes ranging in type and content from a skeletal grid pattern to a relatively complex scene with mountain ranges and a river valley. Results indicated small to null effects for all factors but scene type. Scene type affected a number of performance measures, suggesting that further study to determine transfer of training effects is warranted.

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PREFACE

The entire VTRS research and support staff deserves special commendation for making this experiment possible. In addition, the following individuals merit special mention. Charles Simon provided major consulting on experimental design and data analysis issues. Brian Nelson and Ron Mauk performed much of the data analysis. Charles Simon and Stanley Roscoe provided major editorial input to the report. Gavan Lintern and Fred Berry wrote the pilot briefing material. Paul Rowlands designed and modified visual data bases used in the experiment. Finally, the volunteer pilots who participated in the experiment from VA-174, NAS Cecil Field, Florida, deserve a special word of thanks.

SECTION I

INTRODUCTION

The Visual Technology Research Simulator (VTRS) at the Naval Training Equipment Center (NTEC), Orlando, Florida, has been designed for research on flight simulator requirements for training and skill maintenance. VTRS consists of a fully instrumented Navy T-2C jet trainer cockpit, a six-degree-of-freedom synergistic motion platform and a wide-angle visual system. The visual system is capable of displaying images via target and background projectors subtending 30 degrees below and 50 degrees above the pilot's eye level and can display 160 degrees of horizontal field (Collyer and Chambers, 1978).

The research effort at VTRS began to focus on simulation and training for the air-to-ground bombing task in 1982, after an extensive research program investigating simulator design features for the carrier-landing task (Westra, Simon, Collyer and Chambers, 1982; Westra, 1982). The carrier-landing research was planned around the holistic experimental philosophy proposed by Simon (1973; 1977), and an attempt was made to structure the air-to-ground research program around this philosophy in a similar manner. Fundamental to this approach is the importance of studying as many factors of interest within a single experiment as possible.

The experiment reported here investigated the effects of six simulator variables on the performance of experienced pilots on the 30-degree cone pattern air-to-ground bombing task. This research is the first phase of a program that will include "quasi-transfer" studies in which the simulator is both the training and criterion vehicle, as well as transfer studies involving actual flight tests. The information obtained in this experiment is directly relevant to the design of simulators for skill maintenance and for transition training. These two types of training are considered to be substantially more expensive than undergraduate pilot training (Orlansky and String, 1977).

Six similar factors representing essentially all of the simulator design issues of interest that could be investigated under the (then) current capabilities of VTRS were studied in this experiment. The use of a motion platform was tested against no-simulator motion, and simulated g-forces via a g-seat was tested against no g-force cuing. Distortion correction, specifically, the amount of edge segementation, was investigated and the system's shortest delay, 117 msec delay (from stick input to the completion of the first field of video output), was compared to the 217 msec delay representative of some older simulator visual displays. The background projector offset 40

degrees to the left (to allow visual contact with the target during the initial part of the task) was compared to use of the background projector in the straight ahead position.

Four different scenes were used in the experiment which represented a range of real-world bombing scenarios and a range of display complexity and content. A number of display dimensions were embedded in the scene factor, but these were reserved for future definition and investigation, if necessary. They generally could not be manipulated at the time of the experiment given the VTRS capabilities and time constraints involved.

SECTION II

EXPERIMENTAL PLAN

FLIGHT TASK

The simulated aircraft was a T-2C with Mark-76 25 lb. bombs. The experimental task was a 30-degree cone pattern manual bomb delivery task (see Figures 1 and 2). The task was initialized with the aircraft on the cone 12,938 feet abeam of the target at 8000 feet altitude and heading 180 degrees from the designated run-in line. The aircraft was initialized with power set at 96% in straight-and-level flight at 250 knots airspeed. Elevator trim was set for the 30-degree dive so that back pressure on the stick was required to hold altitude in the initial part of the task.

The task basically consisted of the following contiguous segments: a) flying a curved and level path at 8000 feet altitude towards the run-in line; b) turning into the target approximately 30 degrees from the run-in line; c) rolling aircraft over to 120 degrees pulling the nose down to a 30-degree dive as the run-in line is approached; d) rolling out to wings level into a dive towards the target; e) diving to the target and tracking the pipper (gunsight) on the target to a bomb release at 3000 feet altitude; and f) pulling out of the dive to establish a positive rate of climb. The simulated task was terminated 10 seconds after bomb release. Pilots were instructed to attempt to fly an "optimum" dive with a dive angle of 30 degrees, and bomb release at 3000 feet altitude with airspeed at 350 knots. Further detailed description of the task and error correction procedures is given in Appendix A.

VISUAL CUES. The manual bomb-drop task is primarily a visually referenced task, although the entry segments (a and b) could be done on instruments if the pilot knew the coordinates of the target. Visual reference to the target is necessary from the point of rollover to establish pipper placement and start tracking the target. Target detection *per se* was not an element of the experimental task; all targets in the field-of-view were clearly visible. Other visual cues external to the cockpit involve the landscape or gaming area and are used for altitude and directional reference and general aircraft attitude control.

Scenes or gaming areas used in the experiment consisted of a designated target projected by the visual system target projector with scenery surrounding the target projected by the visual system background projector. The pipper was simulated through the use of a slide projector with a transparency of the mil rings and markings found in some conventional bombsights overlaid on the scenes. All factors varied in the experiment

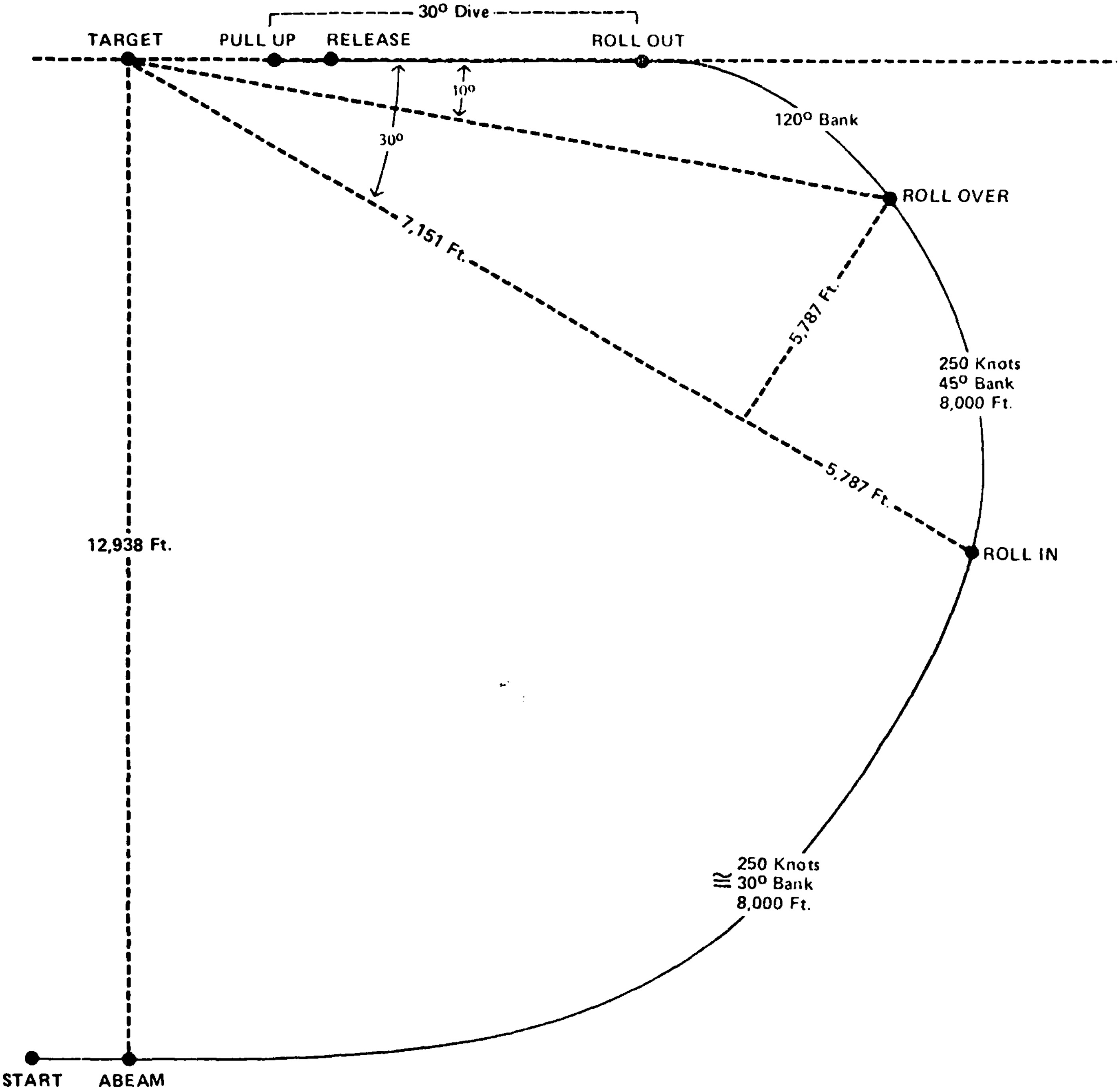

Figure 1. Ground track of flight path for the experimental task.

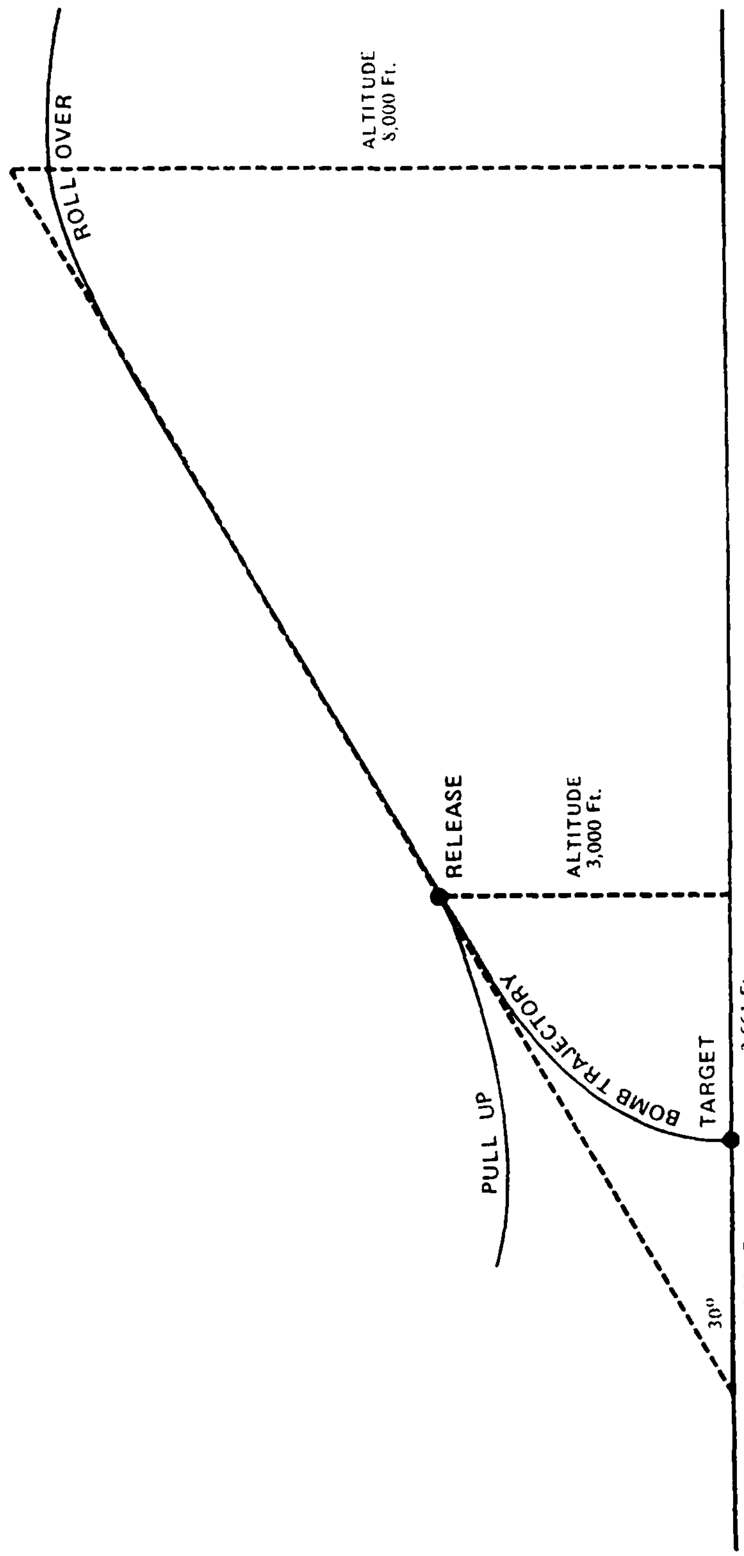

Figure 2. Dive path to the target.

except g-seat and motion directly affect the quality or character of the visual cues to some extent.

FACTORS AND LEVELS

Factor levels were selected to bracket the reasonable range of interest. "High" levels were set at the highest engineering levels currently attainable,while the "low" levels were chosen to be the most degraded form of the factor likely to be employed operationally. In most cases, these levels relate directly to cost and fidelity of the simulation.

SCENE TYPE. Four scenes were selected that were considered to represent a range of real-world air-to-ground bombing scenes across which the effects of the other factors would be measured.* These ranged from a "bare-bones" scene consisting of a grid pattern and a target to a relatively complex scene with a target down in a river valley between mountains. The scenes designated "grid scene," "twin towns," Gila Bend," and "river valley," are shown schematically in Figures 3 through 6. These figures all show a view of the scene taken at 6000 feet altitude in the dive.

Grid Scene. The grid scene had a white grid with one-half mile squares laid over a green background. The target was a white cube located at the center of one of the grid squares. The scene contained 1302 modelled edges, with active edges (those being displayed at any one time) ranging from 639 to 827 for three sample points. It should be noted that this scene could be modelled with far fewer edges and, in fact, the original data base for this scene had only 168 modelled edges with lines ten miles long. These ten-mile lines were segmented in the model into ten one-mile lines so that the scene could be displayed without additional edge segmentation for distortion correction. This will be discussed further under edge segmentation. This scene type is being used on the F-18 Trainer, Device 2E7.

Twin Towns. The twin-towns scene had flat terrain with multicolored fields, roads, towns and streams. It also contained isolated buildings, one of which was designated the target. The scene had 2651 modelled edges with actively displayed edges ranging from 534 to 656. Note that the number of active edges is actually fewer than the far less detailed grid scene.

*The scenes are also of interest in terms of training implications, and visual display parameters involved with the scenes have cost implications for simulator design. The factor levels (scenes) were not defined to allow for the explicit examination of some of the embedded visual parameters involved.

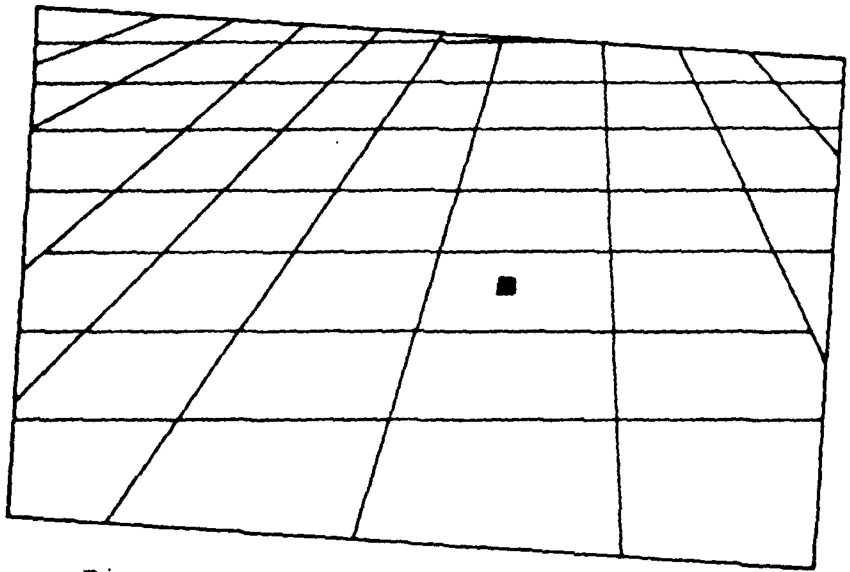

Figure 3. Schematic of grid scene and target. View at 6000 feet altitude in dive.

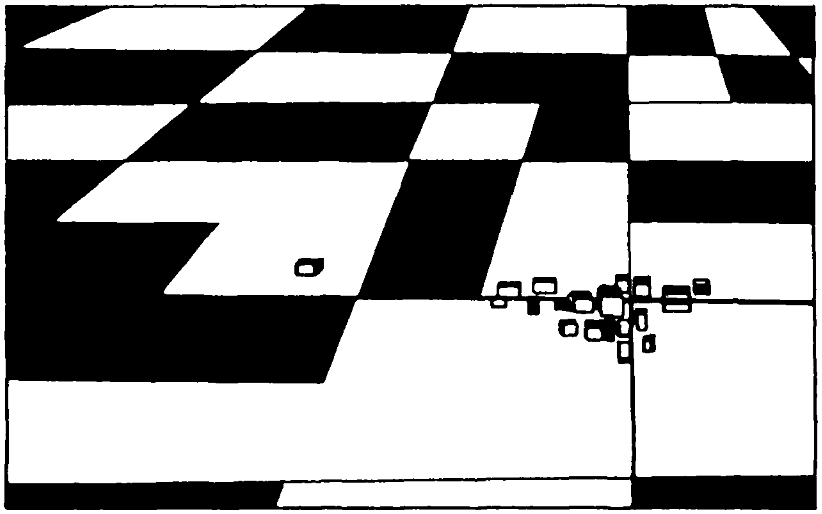

Figure 4. Schematic of twin-towns scene and target. View at 6000 feet altitude in dive.

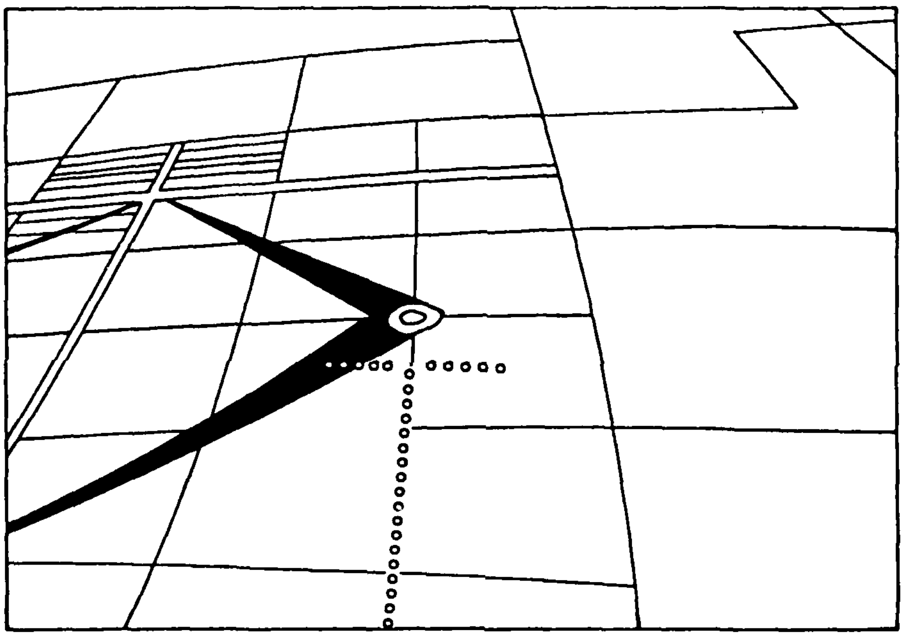

Figure 5. Schematic of Gila Bend scene and target. View at 6000 feet altitude in dive.

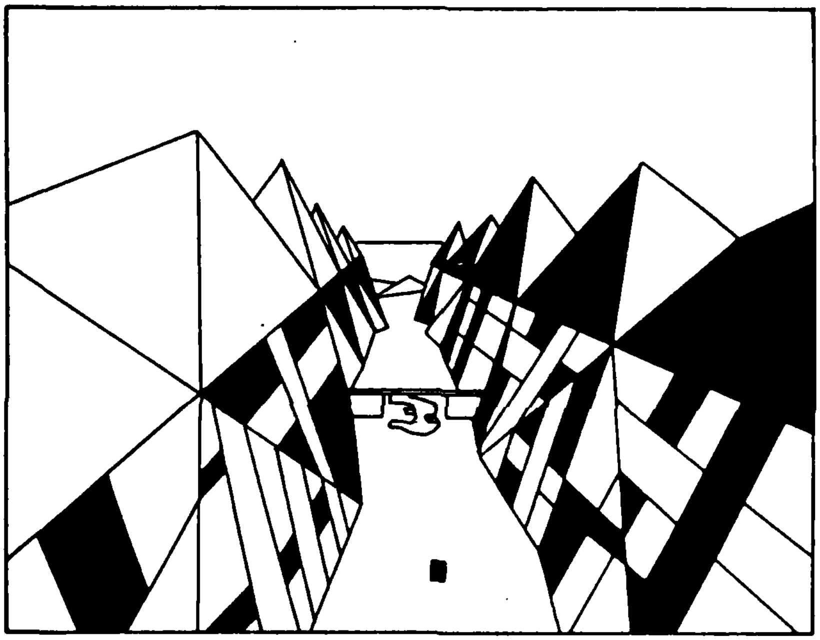

Figure 6. Schematic of river-valley scene and target. View at 6000 feet altitude in dive.

Gila Bend. This scene was a replica of the gunnery range at Gila Bend, Arizona. It contained a large diamond shaped gaming area with a target consisting of different colored concentric circles embedded in a corner of the diamond. The scene contains some explicit orientation lines, including a run-in line leading directly into the target. There are 3126 modelled edges in the data base for this scene, with active edges varying from 774 to 1182. This scene type was used in experiments conducted on the Advanced Simulator for Pilot Training (Waag, 1980) and on Device 2B35 (Hagin, Durall and Prophet, 1979).

River Valley. The river-valley scene was the most complex in terms of number of 3-D objects and modelled edges. It consisted of a river valley with mountain ranges on both sides, with peaks extending to approximately 4000 feet altitude. The river contained bridges and ships and an island with some buildings located near one of the bridges. A white cube placed in the river was used as the target. The scene had 5368 modelled edges and 1010 to 1263 active edges at three sample points. When this scene was used with edge segmentation, there was occasional overload of the 2048 edge capacity background display channel. This was noticeable as "blinking" or "flashing" when the software switched to a lower level of detail but was considered only a minor problem, particularly as the target was not affected.

The most salient features of the scene and targets are summarized in Table 1.

TABLE 1. DESCRIPTIVE FEATURES OF SCENES AND TARGETS

	Twin Towns	Grid Scene	Gila Bend	River Valley
3D Models/Objects	56/77	0/11	23/65	61/303
2D Models/Objects	27/72	4/42	45/134	39/91
Modelled Edges	2651	1302	3126	5368
Active Edges 1[a]	585/850[b]	639/966	955/1294	1010/1226
Active Edges 2	656/1230	827/1255	1182/1868	1263/1815
Active Edges 3	534/970	732/1399	774/1406	1032/1574
Targets:				
Type	3D bldg	artificial cube	conc. circles	artificial cube
Size	100'x50'x75'	100' sides	75', 150' 300' rad.	100' sides
Target Lum.[c]	0.24 fL	1.74 fL	*	1.55 fL
Near Surround Lum.[c]	0.13 fL	0.30 fL	0.04 fL	0.29 fL

[a] Sample 1 taken at 30 degrees from run-in line, sample 2 at 6000-feet altitude in dive, and sample 3 at 3000-feet altitude in dive.

[b] First value is original edges, second value is total edges including those added by edge segmentation.

[c] All measures made at 6000-feet altitude in dive from pilot's eye position.

* Center circle: .33 fL; First band out: 0.76 fL; Second band out: 1.32 fL.

EDGE SEGMENTATION. Edge segmentation involves splitting a modelled edge into a number of equal length segments with correctly positioned vertexes to avoid the appearance of curvature or "scalloping" of straight lines. Note that this is only one element of distortion correction procedures used to display scenes on a curved screen. The system is capable of splitting an edge into as many as 32 segments. The actual number of segments depends upon the outcome from algorithms which determine the amount of segmentation required. The amount of segmentation can be controlled experimentally by a factor which multiplies the computed number of segmented edges by a scaler. The values used in this experiment were 0.5 for the "high" condition, which allowed up to 16 segments per modelled edge, and 0.02 for the "low" condition, which resulted in no-edge segmentation. Since each segmented edge becomes a separate edge for display purposes, this factor obviously can have a major effect on the capacity of the visual system for display. The F-18 Weapons Tactics Trainer, Device 2E7, uses the no-edge segmentation approach in its display distortion correction.

Changes were made to two of the original scene data bases that were in the VTRS inventory order to accommodate the no-segmentation condition. The original twin-towns scene had two roads that traversed most of the field-of-view vertically and horizontally and intersected roughly in the center. These long lines appeared severely bowed without segmentation and were removed from the scene. The grid scene originally had ten-mile long lines that were divided into ten one-mile lines. This increased the number of modelled edges considerably (from 168 to 1302), but still represented a relatively minimal scene. The scalloping appearance of lines was very moderate for most views of the grid pattern without edge segmentation.

Obviously, a practical tradeoff in terms of modelled edges vs segmented edges exists. Little is gained if the number of edges added to a model so that it can be displayed without correction is nearly equal to the number that would be added by an edge segmentation algorithm during display. Thus, the real issue here is not edge segmentation vs none; but rather, how much segmentation is needed. The comparison involves displays of data bases that are considered adequate, or nearly adequate, in uncorrected form vs displays of these data bases that contain additional edges due to the real-time edge-segmentation distortion correction algorithm. The average number of active edges across the four displays was 1321 with edge segmentation and 851 without. Values for each display with and without edge segmentation at three sampled points are given in Table 1.

The practical difference in appearance for the scenes used with and without edge segmentation was generally minor for most viewing angles in the task. The only exception to this is the Gila-Bend scene in which scalloping of the long, uncorrected orientation lines is noticeable. Figure 7 shows a view of the

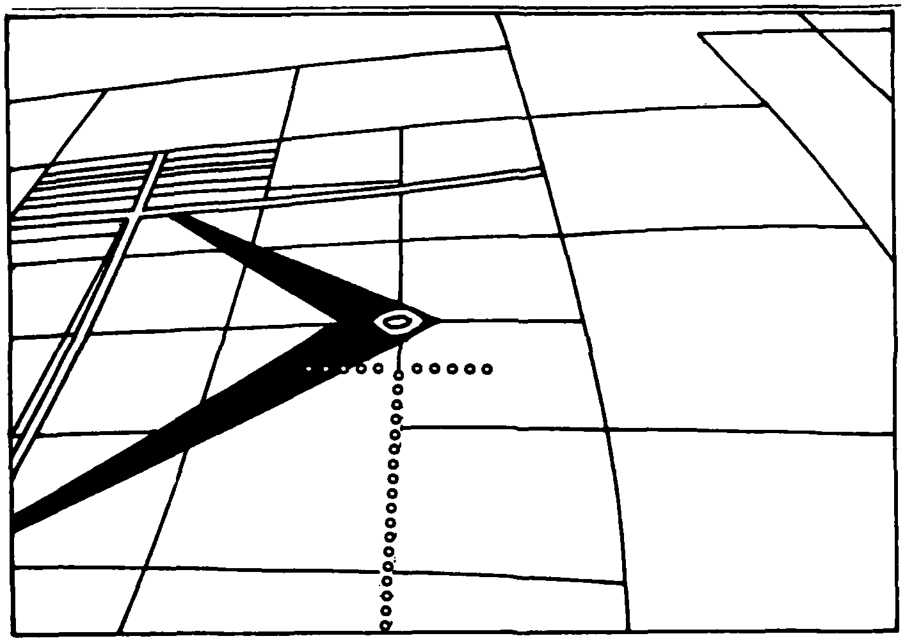

Figure 7. View of Gila Bend scene without edge segmentation distortion correction. View at 6000 feet altitude in dive.

Gila-Bend scene without distortion correction from the same aspect as in Figure 5. Comparison of these figures shows the long vertical and longitudinal lines in the uncorrected display bowing out from the shorter, less distorted lines on which they are overlaid.

SYSTEM LAG. The system visual lag factor (Browder and Butrimas, 1981) high level of 117 msec on average from stick input to the completion of the first field of video output was representative of a 30 Hz computer-simulation update and a 60 Hz CIG update. (The lag actually varies from 100 to 133 msec depending on the point of stick sample.) This response time is faster than that available on most Navy trainers and represents increased computer capacity and cost. The longer visual system lag (low level) average of 217 msec (199 to 232) is representative of a 15 Hz computer-simulation update and 30 Hz CIG update. This response time is representative of the lowest level normally considered in acquisitions of simulators with visual systems.

BACKGROUND OFFSET. The background projector used was capable of displaying a 160-degree horizontal field of view. The background projector was simply slewed 40 degrees to the left of center for the high condition of this factor, giving an effective field-of-view from -120 to +40 degrees. With this condition, a pilot had the target in view at all times during the task including the starting position. The low level of this factor used the straight-ahead position for the background projector, giving an effective horizontal field-of-view of -80 to +80 degrees. Under this condition, pilots could not see the target until about 45 degrees from the run-in line. Since the total field of view is the same for both levels of this factor, there is no significant cost difference. The factor was included in the experiment as a practical matter since there were no experimental data available on this comparison. An offset display has recently been put in operation on an A-4M Trainer.

MOTION. A six-degree-of-freedom 48-inch synergistic motion platform (Browder and Butrimas, 1981) was fully operational for the high level and was stationary for the low level of this factor. This platform is similar to those on the Navy's 27 T-2C Instrument Trainers (Device 2F101) used in Undergraduate Pilot Training (UPT), except that VTRS computation rates are higher for reduced cuing time lag. While it is representative of many older platforms on existing trainers, it does not have the low noise and improved response of new platforms (Agard, 1980).

G-SEAT. A g-seat (Browder and Butrimas, 1981) having 30 pneumatic bellows was operational for the high level and stationary for the low level. The seat was operated with the normal software used to simulate high sustained g-cues without modification. The seat design is similar to that used in the

ASPT, SAAC and several F-4 and F-14 trainers. Its software computations were performed at a 30 Hz rate.

A summary of the factors and levels used in the experiment is given in Table 2.

TABLE 2. SUMMARY OF EXPERIMENTAL FACTORS AND LEVELS

FACTORS	LEVEL SETTINGS	
	"Low"	"High"
Edge Segmentation	No additional edge segmentation	Modelled edges segmented into up to 16 edges
System Lag	217 msec average	117 msec average
Background Offset	±80 degrees background field of view	-120 to +40 degrees background field of view
Motion	Fixed base	Six-degrees-of-freedom
G-Seat	Off	30 pneumatic bellows

Scene Type: Grid pattern, twin towns, Gila Bend, river valley

Turbulence: Held constant at a "light" level
Pilots: Eight experienced air-to-ground fleet pilots

TURBULENCE. Air measurement was held constant at a "light" level of turbulence to represent real-world conditions. Turbulence was generated in the form of pseudo-random "winds" composed of various sinusoidal frequencies and amplitudes acting on the longitudinal, lateral and vertical aircraft axes (Jewel, Jex, Magdaleno and Ringland, 1981). The RMS values of the winds were 3.6 ft/sec for each of the dimensions.

OTHER TRAINING FACTORS. Training aids, augmented simulation features, and other non-simulator factors that might affect learning were not considered for experimental manipulation. To study such factors meaningfully requires an experiment that measures their effects on learning and transfer of training.

PILOTS

The eight Navy pilots who participated in this experiment were all volunteers from VA 174, Cecil NAS, Florida. All were experienced fleet pilots averaging 2311 total flight hours ranging from 1504 to 4500 hours. Flight experience in the preceding six months for all pilots was almost exclusively in A7 aircraft. The pilots averaged 1300 bombing runs with a range of 750 to 5000.

PERFORMANCE MEASURES

The complex and multivariate nature of performance on the air-to-ground task requires that a variety of measures be used to describe and evaluate performance over the range of simulation conditions in the experiment. A large number of summary measures were computed on-line (immediately following a trial) for each trial. The entire list of all summary measures collected is given in Appendix B.

The large number of summary measures available can create difficulties in interpretation without a systematic understanding of the measure set and some categorization and prioritization of the measures. First of all, the measures may be thought of as belonging to the pilot-aircraft control loop and can be broadly categorized as pilot input variables, aircraft output variables and task outcome variables. <u>Pilot input variables</u> such as throttle movement over a segment are typically highly pilot dependent and were not given much weight in the data anlaysis. <u>Aircraft output variables</u> such as roll variability may be reflective of task difficulty but may not be highly related to task outcome within restricted ranges. <u>Task outcome variables</u> directly measure aircraft position relative to the optimum or desired flight path as defined by the task. (Note that for the air-to-ground task, aircraft pitch attitude can be considered both an aircraft output measure and a task outcome measure since dive angle is specified by the task.) In general, effects that were reflected in outcome measures are considered the most important.

A performance measure may be: 1) an integration of a variable over a segment of time, or 2) a single "capture" value taken at a specific point during a trial. Measures that are integrated over a segment provide a within-trial summary indicator and are inherently more reliable than capture scores as they involve performance over a period of time rather than an instant. Any given variable such as lineup deviation from the run-in line during the dive may be integrated over a segment by an overall error score such as root mean square (RMS) error. However, capture values represent the only way in which performance measures may be obtained for the critical end points of the air-to-ground task, i.e., bomb release and bomb impact. The analogue of RMS error for capture values is absolute error which is averaged over trials to obtain mean absolute error. These classes of overall error measures, when applied to task outcome variables, are referred to as quality or "goodness" indicators.

The overall error measure may be further separated into variable and bias components. The bias component of an RMS error score reflects average deviation within a segment and the variable component reflects variability about the average. The capture point analogues are average error and variability of that error taken across trials. In terms of successfully accomplishing the task goals, both bias and variable error are undesirable. However, variable error is presumably more reflective of control difficulty, and this is considered more difficult for a pilot to correct than a bias tendency. Also, a bias effect in the absence of a corresponding overall error effect for a given variable says nothing about differential performance quality. For example, if under one condition the bomb hits are ten feet to the left of target center on average and ten feet to the right of target center under another, and there is no difference in variability about these means, then there is no difference in performance quality. Such an effect would have to be given a low weight in assessing the impact of a factor on task performance. A summary of the various measure categories discussed is given in Table 3.

Data analysis for this experiment was concentrated on several criterion-referenced quality or "goodness" indicators for the dive segment of the task, the bomb release point and bomb impact. The a priori selected set of quality measures used were: 1) RMS error of aircraft position relative to the desired flight path during the dive, 2) absolute error of aircraft states from desired at bomb release, and 3) bomb impact radial miss distance from the target.

RMS ERROR. Three root-mean-square error measurements of aircraft states relative to desired during the dive segment were used:

1) altitude deviations in feet from desired based on distance from target and 30 degree dive angle;

2) lateral deviations in feet from the designated run-in line; and

3) angular deviations in degrees from the designated 30 degree dive angle.

TABLE 3. CATEGORIZATION OF AIR-TO-GROUND PERFORMANCE MEASURES

Location in Pilot-Aircraft Control Loop

Location	Applications	Example
Pilot input	Control technique, workload	Throttle Movement
Aircraft output	Control accuracy, control technique, task difficulty	Roll variability
Task outcome	Criterion of success	Bomb impact deviation from target

Measure Types

		Error Categories		
Temporal	Example	Total	Bias	Variable
Integrated over segment (within trial)	Dive angle error during dive	RMS error	Average deviation within segment	Variability about segment average
Capture value (single value at one "point" of trial)	Dive angle error at bomb release	Absolute error	Average error (over trials)	Variability of error (over trials)

The summary measure list contains scores for the two dive segments, specifically, a segment from 5500 feet to 4500 feet of altitude and a contiguous segment from 4500 feet to 3500 feet of altitude. RMS error values for the same variables from these adjacent segments were usually so highly correlated ($\underline{r} > .9$) that simple averages of the two individual segments were used as dependent measures in this report. Thus, RMS error scores used represent the average of dive segments from 5500 feet to 3500 feet of altitude. It should be noted that, strictly speaking, these average scores are not the actual RMS error values for the total segment, but because of the high correlations will differ only negligibly from true RMS values.

ABSOLUTE ERROR. Three absolute error scores of deviations from optimum aircraft states at bomb release were constructed from measures available in the summary list and used here:

1) absolute deviation in degrees from designated 30-degree angle;

2) absolute deviation in feet from designated release altitude of 3000 feet; and

3) absolute deviation in knots from designated release airspeed of 350 knots.

These measures were treated independently for analysis purposes and, in fact, are nearly statistically independent. Procedurally, however, they are highly related in that an error in one dimension calls for a compensatory correction in another dimension. However, pipper position is also a key component determining corrective compensation. This information was not available in the measure set and, thus, it was not possible to determine deviation from computed "ideal" correction states.

BOMB IMPACT ERROR. The bomb impact radial miss distance in feet was used. This was computed simply from the lateral and longitudinal miss distance components as:

$$\text{radial error} = (x^2 + y^2)^{\frac{1}{2}} \qquad (1)$$

where x and y represent the lateral and longitudinal components of bomb impact deviation from the target. Absolute bomb impact error in the lateral and longitudinal dimensions individually were also used.

OTHER MEASURES. A number of other measures representing aircraft activity and bias and variability components of task outcome were examined. Results of these analyses are presented only for measures showing meaningful effects that did not correlate highly with other measures. Redundancy was determined by examining correlations between measures. Generally, if two measures were correlated greater than 0.9, only one of the

measures were examined. The measures chosen for presentation from all other measures represent a *posterior* set since they were selected based on effect size from a larger set. Although significance levels used for result presentations for these measures were the same as those used for the *a priori* set, caution is advised in interpretation since the *posterior* set will have higher nominal alpha levels.

PROCEDURES

Pilots were given an extensive briefing on the manual air-to-ground bombing task upon arrival at VTRS. Then they flew 32 preliminary trials in the simulator before beginning the experimental trials.

BRIEFING. Pilots were given extensive briefing material in the form of a pamphlet that describes the basics of operation of the simulated T-2C, as well as procedures for the manual air-to-ground bombing task. This briefing pamphlet is given in Appendix A. The briefing material was written by VTRS staff personnel, drawing from an official Navy flight training instruction manual (Flight Training Instructions-TA-4J, 1980), and Vreuls and Sullivan (1982). Pilots were also given a verbal briefing which was essentially a walk-through of the material contained in the pamphlet.

PRELIMINARY TRIALS. Each pilot flew 32 practice trials in two blocks of 16 trials each before starting experimental trials. Preliminary trials were run with g-seat off, background offset, no motion, minimum system lag, and maximum edge segmentation. Eight preliminary trials were run with each of the four scenes. The purpose of these trials was to familiarize the pilots with the equipment and task and to provide enough practice to attain reasonable stability of performance.

"Stability" as used here refers to a consistency in pilots' procedures and method of effectively accomplishing the task. Stability, in this context, did not require that performance reach the "flat" part of the classic learning curve. Learning, as reflected in improved performance, is likely to continue for a long time with difficult perceptual-motor control tasks. Further, and more important, key estimable effects of the experimental design used were generally robust to smooth learning trends.

INSTRUCTIONAL FEEDBACK. After every trial, the pilot was given his bomb release altitude, dive angle and airspeed, and the bomb hit radial miss distance and direction. This was the only feedback information given during the experimental trials. Additional information was given as necessary during preliminary trials to aid in performance stabilization.

SCHEDULING. Pilots were at VTRS in pairs for three days. Each pilot flew 16 trials in a block comprising a session of approximately 40 minutes, and alternated sessions with the other pilot in his pair. Each pilot flew up to four sessions per day until completing all 32 preliminary trials and 128 experimental trials.

EXPERIMENTAL DESIGN

Each of eight subjects were tested on the 32 experimental conditions comprising all combinations of two levels of a five factor factorial. The factors were: g-seat, edge segmentation, system lag, motion, and background offset. The 32 experimental conditions were divided into eight blocks with four conditions per block. The blocks were designated by the capital letters from A to H, and the set of conditions associated with each letter never changed. Subjects were tested four times on each experimental condition before moving on to the next condition. This meant that each subject ran 16 trials per block. The experimental design is summarized in Tables 4 and 5.

Among the eight subjects, the order in which the eight blocks were presented to each was counterbalanced so that each block occurred once in every (block) column position and was preceded and followed by every other block just once. Subjects rested after being tested on a block of four conditions of four trials each.

In addition, the four scenes were assigned to block columns in the order indicated by the Roman numerals in Table 4. Roman numerals I to IV represented scenes Gila Bend, grid pattern, river valley, and twin towns, respectively.

All pilots were tested on scenes presented in the same order, but the block of experimental conditions associated with each scene at any position was different for each. The order of scene presentation was reversed during the second half of the experiment for each subject.

The arrangement shown in Table 4 and described above creates a balanced design that provides the following orthogonal and confounded relationships:

1. All of the main and interaction effects of the five factors can be estimated free of contamination from one another or from average differences among subjects or block positions.

2. The main effects of the five factors were not confounded with the linear, quadratic, or cubic component of the subject-by-trial interaction. Subject-by-trial interaction

occurs when subjects learn at a different rate or in a different pattern. Ordinarily, third degree equations adequately account for changes in human performance (Simon, 1976).

3. Average scene differences were not confounded with any of the other factor effects nor subject effects. Furthermore, they were not confounded with overall linear or cubic trend effects across blocks. Scene differences were partially confounded with quadratic trend.

TABLE 4. SUMMARY DESCRIPTION OF EXPERIMENTAL DESIGN

	TRIAL BLOCKS[a]							
PILOTS	1	2	3	4	5	6	7	8
1	A[b]	B	H	C	G	D	F	E
2	B	C	A	D	H	E	G	F
3	C	D	B	E	A	F	H	G
4	D	E	C	F	B	G	A	H
5	E	F	D	G	C	H	B	A
6	F	G	E	H	D	A	C	B
7	G	H	F	A	E	B	D	C
8	H	A	G	B	F	C	E	D
All Pilots	I[c]	II	III	IV	IV	III	II	I

[a]Each trial block consisted of 16 trials, four trials per condition.

[b]Each letter refers to a set of four conditions from the five two-level factors.

[c]Each Roman numeral represents one of the scenes of the scene-detail factor.

TABLE 5. EXPERIMENTAL CONDITIONS OF BLOCKS SHOWN IN TABLE 4.

Condition Block	Conditions*	Factor Codes
A	abc, d, ae, bcde	a=g-seat on
B	b, acd, ce, abde	b=edge segmentation
C	(1) abcd, bce, ade	c=117 msec lag
D	ac, bd, abe, cde	d=motion on
E	c, abd, be, acde	e=background offset
F	a, bcd, abce, de	
G	ab, cd, ace, bde	
H	bc, ad, e, abcde	

* In each condition, the presence of a letter indicates the presence of the high level of the factor indicated under factor codes. The absence of a letter given under factor codes indicates that the corresponding low level of that factor was present in the condition. It should also be noted that conditions within blocks were rotated across pilots to achieve a highest possible order of balance against trends.

SECTION III

DATA ANALYSIS

Analysis of variance summaries are given in Tables 6 through 11 which show the mean differences between levels of factors as well as the percent variance-accounted-for by each factor or set of terms indicated. The two-factor interactions were separated into four groups and tested omnibus fashion. For example, the five two-factor interactions involving scene type and the other simulator factors were summed into the single term indicated on the tables. The total sums of squares accounted for by the sets of two-way interactions, divided by the total degrees-of-freedom involved, was compared to the residual mean square for tests of significance. Although these omnibus results are shown in the table, each two-way interaction was examined individually and will be discussed where necessary.

PRIMARY CONTRASTS

A one-degree-of-freedom factor comparing mean performance on the first 64 trials vs the second 64 trials across pilots has been included to remove the bulk of any general learning effect from the residual term. All effects were tested against a single residual mean-square term. The residual term is composed of all three-way and higher-order interactions involving the simulator factors and pilots, as well as all trial and replication effects other than the trial block factor described above. A large portion of the residual term (768 of the 926 degrees-of-freedom) is simply an estimate of within-subject trial-to-trial variability. (Additional analyses were performed with an additional "trials-within-condition" factor comparing the first two trials within condition to the second two. Since this comparison generally showed no effect, with one major exception, these results are not shown.)

Although all factors are tested against the single residual term, this is only appropriate if the pilot-by-factor interaction for a particular simulator factor is small. Otherwise, the factor main effect must be significantly greater than the interaction if the main effect is to be generalizable to the population of attack pilots. In most cases, for all factors but scene type, this presents no practical problem for interpreting statistical significance as presented in the tables. Those cases in which there may be an interpretation problem will be discussed.

OTHER INFORMATION. There are certain computations that can be performed to obtain supplementary information with which to interpret the data. The numbers required for these analyses are available in the tables. The <u>mean performance</u> for high and low

levels of any two-level factor can be obtained by taking the grand mean shown at the bottom of each column and to it add (high level) or substract (low level) half of the mean difference for that factor. (Means are shown explicitly for the levels of the scene-type factor.) The sign of the mean difference must be taken into consideration in this calculation since the mean of the low condition was always subtracted from the mean of the high condition to obtain the mean difference. A negative RMS of absolute error mean difference indicates better performance with the factor's highest level.

F-ratios for a particular effect can be calculated using the percentages in the table. The numerator of the ratio is the percent variance-accounted-for by an effect divided by its degree of freedom, and the denominator is the residual percent variance accounted for divided by its degree-of-freedom. Significance is indicated at 0.05 and 0.01 levels. For these results, it is suggested that 0.01 is an appropriate level of significance providing some compensation for the multiple tests and measures involved.

INTERPRETATION STANDARDS. That an observed difference between two conditions is or is not statistically significant provides little information regarding the practical significance. Some outside "real-world" standards are needed to evaluate the data. One guideline given by Cohen (1977, p.25-27) suggests using percent variance-accounted-for and suggests that effect size labels of small, moderate and large be associated with values of 1%, 6% and 14%, respectively. Although these values are arbitrary and arguable, the author feels they are reasonably sound "ballpark" values to use.

Mean differences that would account for a "moderate" 5% of the experimental variance for certain key quality measures are: 145 feet for RMS dive lineup error, 100 feet for RMS dive altitude error, 0.8 degree for RMS dive pitch error, and 37 feet for bomb hit radial error. It should be noted that this experiment was quite powerful and could detect effects of this magnitude at the .01 level with virtual certainty. In fact, effects accounting for as little as 0.5% of the total variance were usually detected as significant at the .05 level.

The "moderate" values suggested above are not absolute, as they depend on experimental estimates and the experimental environments. Although it is believed the values are reasonable, it still would be useful to compare obtained effect estimates with fleet established values that could be translated into fleet or mission effectiveness. Unfortunately, these values are not simple to obtain or establish, but discussions with instructor pilots at Cecil Field, Florida, have suggested some "meaningful" categories for bomb-drop radial miss distances. Differences in miss distance of 40 feet, 70 feet and 100 feet are considered small, moderate and large, respectively.

SECTION IV

RESULTS

GENERAL FINDINGS

The simulator factors other than scene type had little or no practical effect on quality scores (Tables 6, 7 and 8). Although there were statistically reliable effects for g-seat and background offset, these effects accounted for less than 1% of the variance. The scene-type factor generally showed reliable differences between the scenes for all quality measures, but in only a few were these differences any greater than "small" in practical magnitude. Variance-accounted-for by pilot mean differences was large. The variance-accounted-for by pilots was typically much greater than all other experimental main effects combined. Pilot differences on the one factor that had a consistent effect (scene type) were also relatively large, creating interactions often large enough to restrict the generalizability of the scene-type effects.

Other pilot interactions were generally smaller, and this is not surprising, since the other main effects were typically trivial. There were, however, some statistically reliable pilot interactions with other factors which, in the case of no-factor main effect, indicates that some pilots perform better with the high level and some with the low level of the factor. The trial block factor showed little effect on quality measures except for the bomb-drop-miss distances. This suggests little "learning" over the course of the experiment, and considering the experience level of the pilots and the large number of pre-experimental trials, this finding was not unexpected. Still, there was improvement even at the generally high experimental level of performance in the bomb-drop scores over the course of the experiment. (As noted previously, general learning that may have occurred is not confounded with other factor main effects and two-way interactions.) Tables 9, 10 and 11 present analyses of variance for posterior selected scores that highlight and essentially describe simulator factor effects not described by the *a priori* selected quality measures. With the exception of the RMS dive roll error, all the measures shown in Tables 9 to 11 are bias scores. For these scores, very large pilot effects can again be noted, as well as some substantial scene type effects. But, it can also be seen that the motion and background offset factors produced some biases that were not generally reflected in the quality measures.

Motion, for example, produced a 52-foot bias in the horizontal dimension of bomb-drop-miss distance, but the means with and without motion are approximately equidistant from the center of the target and, thus, there is no difference in

TABLE 6. ANALYSIS OF VARIANCE SUMMARIES FOR DIVE QUALITY MEASURES (5500-3500 FEET ALTITUDE)

Source of Variance	LEVELS "High"	"Low"	df	RMS DIVE ERROR Alt (ft)	Line-up (ft)	Dive Angle
Scene Type			3	(0.6)[a]	(1.4)**	(0.7)**
Grid				302.1[b]	375.5	2.98
Twin Towns				287.6	451.6	2.74
Gila Bend				307.1	372.7	2.48
River Valley				264.9	450.6	2.58
G-seat	On	Off	1	7.0(-)	61.6(0.9)	-0.08(-)
Background Offs	-40 degrees	0 degrees	1	-29.1(-)*	-31.6(-)	0.00(-)
Motion	On	Off	1	0.1(-)	4.6(-)	-0.19(-)
System Lag	117 msec	217 msec	1	13.5(-)	-8.0(-)	0.11(-)
Edge Segmen.	16/edge	None	1	-4.4(-)	-0.6(-)	0.01(-)
Scene 2FI			15	(1.2)	(2.2)*	(0.6)
Other 2FI			10	(-)	(1.9)**	(0.9)
Main Trial Blk	1st 64	2nd 64	1	8.6(-)	26.0(-)	-0.11(-)
Pilots			7	(10.0)**	(6.5)**	(43.0)**
Pilots by Scene			21	(4.9)**	(11.0)**	(3.3)**
Other Pilot 2FI			35	(6.5)**	(3.4)	(3.3)**
Residual			926	(75.7)	(72.3)	(48.0)
Grand Mean				290.4	412.6	2.70

[a] Values in parenthesis are percent variance accounted for in the experiment. Values less than .5 are indicated by a dash (-).

[b] Mean scores shown for individual scenes. Other values for two-level factors are mean differences, i.e., mean for high level condition minus mean for low level condition.

* p .05
** p .01

TABLE 7. ANALYSIS OF VARIANCE SUMMARIES
FOR BOMB RELEASE QUALITY MEASURES

Source of Variance	LEVELS "High"	"Low"	df	ABSOLUTE ERROR Alt (ft)	Dive Angle (deg)	Airspeed (kn)
Scene Type			3	(0.6)*[a]	(0.7)*	(2.4)**
Grid				181.5[b]	2.14	7.46
Twin Towns				214.2	2.09	5.89
Gila Bend				202.3	2.21	6.46
River Valley				181.0	1.85	8.03
G-seat	On	Off	1	1.3(-)	0.10(-)	0.13(-)
Background Offs	-40 degrees	0 degrees	1	6.2(-)	-0.09(-)	0.45(-)
Motion	On	Off	1	-13.1(-)	-0.05(-)	0.03(-)
System Lag	117 msec	217 msec	1	10.2(-)	0.10(-)	0.58(-)
Edge Segmen.	16/edge	None	1	-0.6(-)	-0.04(-)	0.09(-)
Scene 2FI			15	(1.2)	(2.0)	(1.0)
Other 2FI			10	(0.7)	(-)	(0.5)
Main Trial Blk	1st 64	2nd 64	1	-25.4(0.5)**	-0.14(-)	0.23(-)
Pilots			7	(25.0)**	(6.5)**	(12.3)**
Pilots by Scene			21	(2.6)*	(3.4)*	(6.0)**
Other Pilot 2FI			35	(2.9)	(5.0)*	(1.9)
Residual			926	(66.2)	(81.5)	(75.2)
Grand Mean				194.7	2.07	6.96

[a] Values in parenthesis are percent variance accounted for in the experiment. Values less than .5 are indicated by a dash (-).

[b] Mean scores shown for individual scenes. Other values for two level factors are mean differences, i.e., mean for high level condition minus mean for low level condition.

* p .05
** p .01

TABLE 8. ANALYSIS OF VARIANCE SUMMARIES FOR BOMB IMPACT QUALITY MEASURES

Source of Variance	LEVELS "High"	"Low"	df	ABSOLUTE ERROR IN FEET Radial	Horizontal	Longitudinal
Scene Type			3	(1.5)**[a]	(2.4)**	(1.0)**
Grid				137.8[b]	70.6	103.6
Twin Towns				118.3	52.7	94.5
Gila Bend				144.9	60.5	118.4
River Valley				136.5	71.4	100.7
G-seat	On	Off	1	15.7 (0.9)**	1.8(-)	15.9(0.9)**
Background Offs	-40 degrees	0 degrees	1	2.0 (-)	4.0(-)	-0.7(-)
Motion	On	Off	1	-0.8 (-)	-4.0(-)	2.8(-)
System Lag	117 msec	217 msec	1	-3.9 (-)	0.4(-)	-3.8(-)
Edge Segmen.	16/edge	None	1	2.4 (-)	1.3(-)	2.0(-)
Scene 2FI			15	(1.2)	(4.7)**	(1.0)
Other 2FI			10	(1.6)	(1.4)	(1.1)
Main Trial Blk	1st 64	2nd 64	1	23.6 (2.1)**	8.6(0.7)**	20.9(1.5)**
Pilots			7	(2.5)**	(1.4)*	(2.7)**
Pilots by Scene			21	(3.8)**	(5.0)**	(3.6)*
Other Pilot 2FI			35	(3.9)	(5.1)*	(3.8)
Residual			922	(82.8)	(78.9)	(84.0)
Grand Mean				134.4	63.8	104.3

[a] Values in parenthesis are percent variance accounted for in the experiment. Values less than .5 are indicated by a dash (-).

[b] Mean scores shown for individual scenes. Other values for two-level factors are mean differences, i.e., mean for high level condition minus mean for low level condition.

* p .05
** p .01

TABLE 9. ANALYSIS OF VARIANCE SUMMARIES
FOR SELECTED SCORES: DIVE SEGMENT
(5500-3500 FEET) BIASES

Source of Variance	LEVELS "High"	"Low"	df	AVERAGE ERROR Alt (ft)	Line-up (ft)	Airspeed (kn)
Scene Type			3	(1.1)**[a]	(11.9)**	(4.7)**
Grid Scene				-44.7[b]	84.7	14.9
Twin Towns				-39.7	270.9	13.9
Gila Bend				-113.6	142.0	12.2
River Valley				-119.3	-215.2	18.0
G-seat	On	Off	1	7.3 (-)	42.3(-)	-0.8(-)
Background Offs	-40 degrees	0 degrees	1	75.8 (1.2)**	21.1(-)	-1.0(-)
Motion	On	Off	1	-36.3 (-)	80.9(0.6)**	1.7(0.7)**
System Lag	117 msec	217 msec	1	13.7 (-)	11.2(-)	-0.6(-)
Edge Segmen.	16/edge	None	1	-8.9 (-)	-15.8(-)	0.4(-)
Scene 2FI			15	(1.6)	(1.7)*	(0.9)
Other 2FI			10	(0.6)	(1.4)**	(-)
Main Trial Blk	1st 64	2nd 64	1	4.8 (-)	111.1(1.2)**	2.2(1.3)**
Pilots			7	(21.0)**	(21.6)**	(29.3)**
Pilots by Scene			21	(6.5)**	(5.6)**	(7.6)**
Other Pilot 2FI			35	(3.6)*	(2.5)	(3.5)**
Residual			926	(64.2)	(53.4)	(51.1)
Grand Mean				-79.3	70.6	14.8

[a] Values in parenthesis are percent variance accounted for in the experiment. Values less than .5 are indicated by a dash (-).

[b] Mean scores shown for individual scenes. Other values for two-level factors are mean differences, i.e., mean for high level condition minus mean for low level condition.

* p .05
** p .01

TABLE 10. ANALYSIS OF VARIANCE SUMMARIES FOR SELECTED BIASES AT BOMB RELEASE

Source of Variance	LEVELS "High"	"Low"	df	AVERAGE VALUE Heading (deg)	Dive Angle (deg)	Power (deg)
Scene Type			3	(7.7)**[a]	(2.2)**	(1.7)**
Grid				-1.8[b]	-30.2	85.7
Twin Towns				-3.0	-30.3	84.7
Gila Bend				-1.4	-29.7	85.4
River Valley				0.5	-29.3	85.8
G-seat	On	Off	1	-0.4(-)	-0.1(-)	-0.2(-)
Background Offs	-40 degrees	0 degrees	1	-0.1(-)	-0.6(1.6)**	0.0(-)
Motion	On	Off	1	-1.1(1.5)**	0.3(-)	0.7(1.2)**
System Lag	117 msec	271 msec	1	0.0(-)	-0.2(-)	0.0(-)
Edge Segmen.	16/edge	None	1	0.2(-)	0.1(-)	0.2(-)
Scene 2FI			15	(1.3)	(1.6)	(2.0)*
Other 2FI			10	(1.5)**	(0.7)	(1.3)
Main Trial Blk	1st 64	2nd 64	1	-1.0(1.3)**	0.2(-)	-0.1(-)
Pilots			7	(22.4)**	(2.2)**	(18.2)**
Pilots by Scene			21	(5.9)**	(6.1)**	(4.7)**
Other Pilot 2FI			35	(1.7)	(3.2)	(2.5)
Residual			926	(56.2)	(71.7)	(68.2)
Grand Mean				-1.4	-29.9	85.4

a Values in parenthesis are percent variance accounted for in the experiment. Values less than .5 are indicated by a dash (-).

b Mean scores shown for individual scenes. Other values for two-level factors are mean differences, i.e., mean for high level conditions minus mean for low level condition.

* p .05
** p .01

TABLE 11. ANALYSIS OF VARIANCE SUMMARIES FOR RMS ROLL ERROR IN DIVE (4500-3500 FEET ALTITUDE) AND BOMB IMPACT BIASES

Source of Variance	LEVELS "High"	"Low"	df	AVERAGE IMPACT ERROR (ft) Horizontal	Longitudinal	RMS ERROR Roll (deg)
Scene Type			3	(10.5)**[a]	(2.8)**	(4.2)**
Grid				-41.2[b]	31.6	5.4
Twin Towns				10.5	31.3	5.0
Gila Bend				25.3	39.3	4.6
River Valley				18.9	-17.3	6.4
G-seat	On	Off	1	1.6 (-)	-3.9(-)	0.2(-)
Background Offs	-40 degrees	0 degrees	1	19.2 (1.4)**	18.5(0.5)*	0.3(-)
Motion	On	Off	1	-52.2 (10.3)**	-9.0(-)	-0.1(-)
System Lag	117 msec	217 msec	1	4.1 (-)	-1.2(-)	-0.7(1.1)**
Edge Segmen.	16/edge	None	1	-5.1 (-)	6.1(-)	-0.2(-)
Scene 2FI			15	(1.2)	(0.5)	(0.8)
Other 2FI			10	(0.5)	(0.7)	(0.7)
Main Trial Blk	1st 64	2nd 64	1	-1.6 (-)	6.4(-)	-0.0(-)
Pilots			7	(7.1)**	(1.2)	(19.9)**
Pilots by Scene			21	(6.3)**	(6.4)**	(5.2)**
Other Pilot 2FI			35	(3.4)	(3.5)	(3.0)
Residual			922[c]	(59.1)	(84.1)	(64.4)
Grand Mean				3.4	21.2	5.4

[a] Values in parenthesis are percent variance accounted for in the experiment. Values less than .5 are indicated by a dash (-).

[b] Mean scores shown for individual scenes. Other values for two-level factors are mean differences, i.e., mean for high level condition minus mean for low level condition.

[c] Degrees of freedom are 926 for RMS roll error.

* p .05
** p .01

quality of performance. The system lag effect was only found in measures of dive roll error (from zero degrees), such as the one shown on Table 11. Distortion correction did not appear to have an effect of any kind, however small.

EFFECTS OF INDIVIDUAL FACTORS

SCENE TYPE. There were differences in performance among the various scenes for most measures. The bias differences indicated in Tables 9, 10 and 11 clearly indicate that approach angles were dependent on scene type. Lineup, airspeed and altitude differed in the dive, resulting in corresponding differences in heading, dive angle, and power setting at bomb release, and horizontal and longitudinal biases for the bomb impact. These differences were particularly substantial in the lineup (horizontal) dimension of the approach.

This finding was not surprising since the scenes differed in a number of ways. The run-in line, for example, was explicit in the Gila Bend scene, and grid lines were parallel to an imaginary run-in line in the grid pattern scene. The twin-towns and river-valley scenes did not have "artificial" lineup cues. Further, although pilots were instructed to align the aircraft with the defined run-in line for the dive, a target can be successfully attacked from any direction. Thus, there is no criterion outcome reference to hold the pilots to a specific lineup flight path, and it could be expected that pilots would develop unique approach angle strategies and that the scene used would affect these strategies.

More important is the question of how quality of performance was affected by the scenes. Tables 6, 7 and 8 show quality affected to a lesser extent. The Gila Bend scene which had an artificial run-in line, and the grid scene which had longitudinal lines aligned with the imaginary run-in line, produced the best RMS dive lineup error scores. However, the twin-towns scene produced the best airspeed error scores at bomb release and the best bomb impact scores, in both the horiziontal and longitudinal dimensions, as well as overall. The radial miss distance was 21.4 feet less with the twin-towns scene than the average miss distance of the other three scenes.

All of the main effect differences are mitigated by the presence of significant pilot-by-scene interactions. In other words, the effects are so inconsistent from pilot to pilot that generalizability to a pilot population is compromised, in some cases considerably. Nevertheless, it must be concluded that the scene type produced definite effects. This factor warrants considerable further investigation, both in terms of further definition of the visual dimensions involved in the scenes, and the training impact of these dimensions.

The interactions of scene type with the other simulator factors appears negligible for most measures. This is not surprising since the other factors did not appear to have much impact on performance. One exception was with the bomb impact absolute error measure in the horizontal dimension where a rather large x-type interaction occurred (direction of effect is reversed in the cells defined by the factor combinations). This interaction involved motion and will be discussed in connection with that factor.

G-SEAT. Performance was worse for dive-lineup and bomb-impact errors in the longitudinal dimension with the g-seat on. Although these effects are not large, they are quite reliable and involve variability almost entirely (as opposed to bias). Clearly, the g-seat is giving cues that actually interfere with performance either by producing incorrect cues or spurious cues resulting in overcontrol. The case for spurious cuing was supported by further investigation of the effect over trials within conditions. (Recall that four trials were run per condition.) These analyses showed that the entire g-seat effect took place in the first two trials of a condition, suggesting an "onset" effect that quickly subsided.

BACKGROUND OFFSET. Offsetting the displays 40 degrees to the left, compared to the straight ahead position (80 degrees), resulted in some minor bias differences. The most substantial of these was for altitude during the dive with a corresponding bias in pitch (dive angle) at bomb release. There were also biases in both the horizontal and longitudinal dimensions of bomb impact. As far as quality of performance is concerned, there is only a suggestion of better performance in the altitude and lineup aspects of the dive with the background in the offset position. Overall, the effect of this factor must be regarded as small, with a slight advantage to the displays with background in the offset position.

MOTION. The motion factor produced no main effect on performance quality, although there was one substantial interaction effect with scene type to be discussed later. The motion factor did produce some considerable bias. There was an 80.9-foot bias difference in dive lineup, a corresponding 1.1-degree difference in heading at bomb release and a 52.2-foot difference in the horizontal dimension of bomb impact. The 52-foot difference in bomb impact was roughly equally divided left and right of target center so there was no difference in absolute error. There were also considerable bias differences in the horizontal dimensions for scenes, so it might be expected that if the motion effect were analyzed by scene, qualitative differences would emerge. This turns out to be true and is reflected in the 4.7% variance-accounted-for by the scene type two-factor interactions

for bomb impact absolute horizontal error shown in Table 8. Most of this amount (3.6%) was accounted for by the motion-by-scene type interaction.

Table 12 below gives the absolute horizontal bomb impact errors for motion by scene type and shows that the motion platform gives an average 14.7-foot improvement with the twin towns, Gila Bend, and river valley scenes, but a 28.2-foot decrement with the grid scene.

TABLE 12. ABSOLUTE BOMB IMPACT HORIZONTAL ERROR FOR MOTION-BY-SCENE TYPE

	Grid	Twin Towns	Gila Bend	River Valley
Motion On	84.7	46.3	50.1	66.1
Motion Off	56.5	59.1	70.9	76.7

Since these differences have been created by main effect biases, it is probably prudent not to give this too much weight. It is concluded that the presence of motion compared to no-motion resulted in a lineup bias, apparently caused by differences in the perception of turn rate, but no appreciable or consistent differences in the quality of performance.

SYSTEM LAG. The primary effect detected as a result of the longer lag time was an increase in roll variability in the dive. (There were also effects on some stick measures, but these are not reported here.) This difference is reflected in the RMS roll error measure shown in Table 9. This effect parallels the lag effect found for the carrier-landing task (Westra, et al., 1982). As none of the outcome measures of quality was affected by the factor, the effect must be regarded as fairly small in a general sense. Roll variability may be reflective of workload, however, and under this interpretation, the task is more difficult with the longer lags. Note also that the river-valley scene is more "difficult" than the other three scenes in this sense, and this difference is greater than the system lag difference.

EDGE SEGMENTATION. There were simply no effects as a result of the different amounts of edge segmentation. This factor involves the question of how long an edge can be before it is desirable to segment it. Recall that for the grid-scene data base the modelled edges were reduced to one mile in length and some long roads were removed from the original twin-towns data base. Therefore, modelled edges for all scenes were one mile or less in length except for the orientation lines in the Gila Bend scene.

Thus, it can be tentatively claimed that segmentation of background scene edges less than one-mile long, whether by a real-time display edge segmentation algorithm or by modifying the data base, is not necessary for the cone pattern air-to-ground bombing task. This would obviously not generalize to other tasks in which visual discrimination at much closer ranges would be necessary. However, it does suggest that simpler, lower cost distortion correction methods may not impact performance on certain tasks. In the F-18 Weapons Tactics Trainer edge segmentation has not been applied to the terrain representation for air-to-air combat training, and the result obtained here supports this lower cost method.

SECTION V

CONCLUSIONS

This experiment was conducted to define simulator design requirements for pilot skill maintenance and transition training for the cone pattern dive bombing task. Five pairs of simulator components were compared across four bombing scenes to determine their effects on performance in the simulator by pilots with fleet experience. The study did not involve any aspect of low level flight such as would be part of the air-to-ground bombing task with a pop-up maneuver. The study does not directly pertain to the training of novice pilots.

The main conclusion to be drawn is that the five simulator factors (other than scene type) had a very minor overall impact on performance. Pilot differences generally accounted for far more variance in performance than the five other factors combined. This implies that a point of diminishing returns has been reached with respect to further improvements in simulator fidelity for air-to-ground skill maintenance and transition training. It appears that added realism (beyond the low levels of the five factors) should not be purchased at the expense of lower reliability or higher acquisition and life cycle costs.

The scene-type factor did have substantial effects on a number of measures. This factor has two very distinct aspects which makes effects difficult to interpret.

First, it represents a range of scenes from impoverished to complex. Unlike the carrier-landing task in which there is only one scene--albeit difficult--the air-to-ground task involves a variety of "gaming areas" and, thus, an added dimension to consider when doing research on the task. In this sense, the factor properly filled its role of providing an appropriate range across which to measure the effects of the other factors. In this sense also, considerable differences in performance among the scenes are expected, just as in the real world for scenes of different types.

Second, the factor is of interest for its training implications. In this role, it is ill-defined since there are many embedded visual dimensions. Further, it is not possible to infer training value *per se* for the scene factor based on this performance experiment (even if the embedded dimensions were sorted out). A transfer-of-training experimental paradigm, with specification of a criterion-task scene or scenes, would be necessary to make such inferences.

EVALUATING PERFORMANCE EFFECTS

All of the factors except distortion correction had some effect on at least one measure of performance. Certain conditions enhanced the mission outcome quality, while others appeared to affect only secondary criteria, and still others produced statistically significant, but not necessarily practical effects. There was a subjective attempt to order the factors in terms of overall impact on performance. This was not a simple matter and bears some reflection on the general approach.

Both size and type of effects were taken into account so straightforward multivariate analysis procedures such as discriminant analyses provided only partial solutions in achieving an overall ordering. Measures were weighed by type with outcome quality measures (e.g., bomb impact radial error) given the most weight, then aircraft output measures (e.g., roll variability), then pilot input measures (e.g., elevator movement per second). In addition, if the effect involved a bias, consideration was made of the differential quality indicated. A bias that was equally divided in deviation from target, so that there was no differential quality, was given low weight.

Basically, effects occurred that were considered to represent three levels of overall impact. The scene-type factor was considered to have a moderate impact. G-seat, motion, background effect, and system lag were considered to have small overall impacts. Ordering is questionable within this group because of the small effects involved, effects on secondary measures with no associated difference in outcome quality, and bias effects with no differential quality. Finally, the distortion-correction factor was placed in a category that could be labeled none.

INDIVIDUAL FACTOR EFFECTS

SCENE TYPE. The different scenes resulted in effects on a variety of performance measures. Notable among these was better run-in lineup performance with the Gila-Bend and grid-pattern scenes, compared to the twin-towns and river-valley scenes. Since the former scenes had specific run-in line cues, there is an implication for training value in this dimension of the displays. Probably the most notable effect was the clearly better bomb impact scoring with the twin-towns scene. It is thought that this was partly due to the greater perception of stability afforded by the three-dimensional building used as a target in this scene. Still, the twin-towns scenes had the smallest number of active edges of the four scenes, even less than the grid scene. If one had to pick one scene to use, the twin-towns scene certainly represents a "best buy" in terms of cost, fidelity, and effectiveness.

G-SEAT. Use of the g-seat had a negative effect on performance. Dive lineup error and bomb impact longitudinal error were greater with the g-seat on. These effects were small (less than one percent of the variance accounted for in the respective measures) and temporary. These effects were not seen in the third and fourth trials of the conditions, suggesting that the g-seat onset caused some overcontrol which quickly dissipated.

SYSTEM LAG. Roll variability in the dive was slightly greater with the longer (217 msec) system lag time. Task outcome measures were not affected by this factor. It should be noted that independently performed multivariate analyses (Wooldridge and Nelson, 1983), which include stick measures (they have been largely ignored in this presentation), showed system lag having the largest multivariate effect (not including scene type). There was increased stick activity with the longer lag, which was reflected in greater roll variability, but nothing else. It is concluded that the factor had an effect on task difficulty as reflected in certain measures, but the increase in difficulty was not great enough to affect task outcome.

MOTION. The use of the simulator-motion platform, compared to no-platform motion, resulted in related biases in the lateral dimension of the dive, bomb release and bomb impact. This bias apparently occurred because of differential perception of turn rate due to the motion factor. These biases at bomb impact were substantial, but resulted in no differential performance quality. Other minor biases also occurred as a result of motion but, generally, without having appreciable or consistent effect on the quality of performance.

BACKGROUND OFFSET. The background offset factor also produced some minor bias differences. There was only a suggestion of differential quality, with the advantage going to the background projector in the offset position. Since this factor does not represent a large cost driver in simulator design, it is recommended simply that background offset capability be used, if available, for this task. Further study of this factor is not warranted for tasks of this general type, but may be for other types.

EDGE SEGMENTATION. There were no effects due to edge-segmentation distortion correction as defined in this experiment. Modelled edges in the background scenes longer than one mile were not used (with a few exceptions) and, in fact, two original data bases were modified to achieve this. Thus, the implication is that data bases containing edges not longer than one mile can be displayed without edge-segmentation software and hardware for the air-to-ground task, although some shorter lines in the vicinity of the target may be desirable for certain scenarios.

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APPENDIX A

BRIEFING: ORDNANCE DELIVERY IN THE VISUAL TECHNOLOGY RESEARCH SIMULATOR. THIRTY DEGREE BOMB

THE SIMULATOR

The cockpit of the VTRS represents a T-2C aircraft. Because the T-2 is not used for air-to-ground bombing, we have adjusted the parameters of a 30 degree bombing pattern as flown by attack aircraft to enable the task to be executed in our simulator.

Figure A8 is a diagram of the instrument panel. Note the positions of the instruments that are marked. The power levels will be to your left. You will be told about rudder pedal adjustment, seat height adjustment, head rest operation, fire control systems, and dome lighting when you first enter the cockpit.

If you have not used a bomb sight, refer to Figure A9. The bomb sight is calibrated in mils (a mil is an angular unit that subtends one foot at a distance of 1000 feet) and has been preset to the desired depression angle. The sight is graduated in ten mil increments both vertically and horizontally. Three solid circles are placed at the 25, 50 and 100 mil graduations. A solid dot known as the "pipper" forms the center of the sight. Two cross hair lines bisect the sight diagonally.

BOMB PATTERN

You will fly the 30 degree cone pattern used by Marine Corps and Navy pilots for air-to-ground ordnance delivery (bombs/rockets). The cone is taught to emphasize the idea that an effective run can actually be made from any direction. For any given target and dive angle, the union of all the possible run-in flight paths will form a cone over the target. In a combat environment you would maneuver your aircraft so as to intercept this cone from any direction. Figures A10 and A11 show a side view and a top view of the 30 degree cone pattern. This pattern is used for 30 degree bomb and rocket deliveries. Pattern altitude and airspeed are adjusted for different aircraft types. The bomb release point is computed to provide the pilot a safe separation from exploding fragments and allow sufficient altitude for a safe recovery from the dive. The cone pattern by virtue of its versatility is easily adaptable to a changing combat situation.

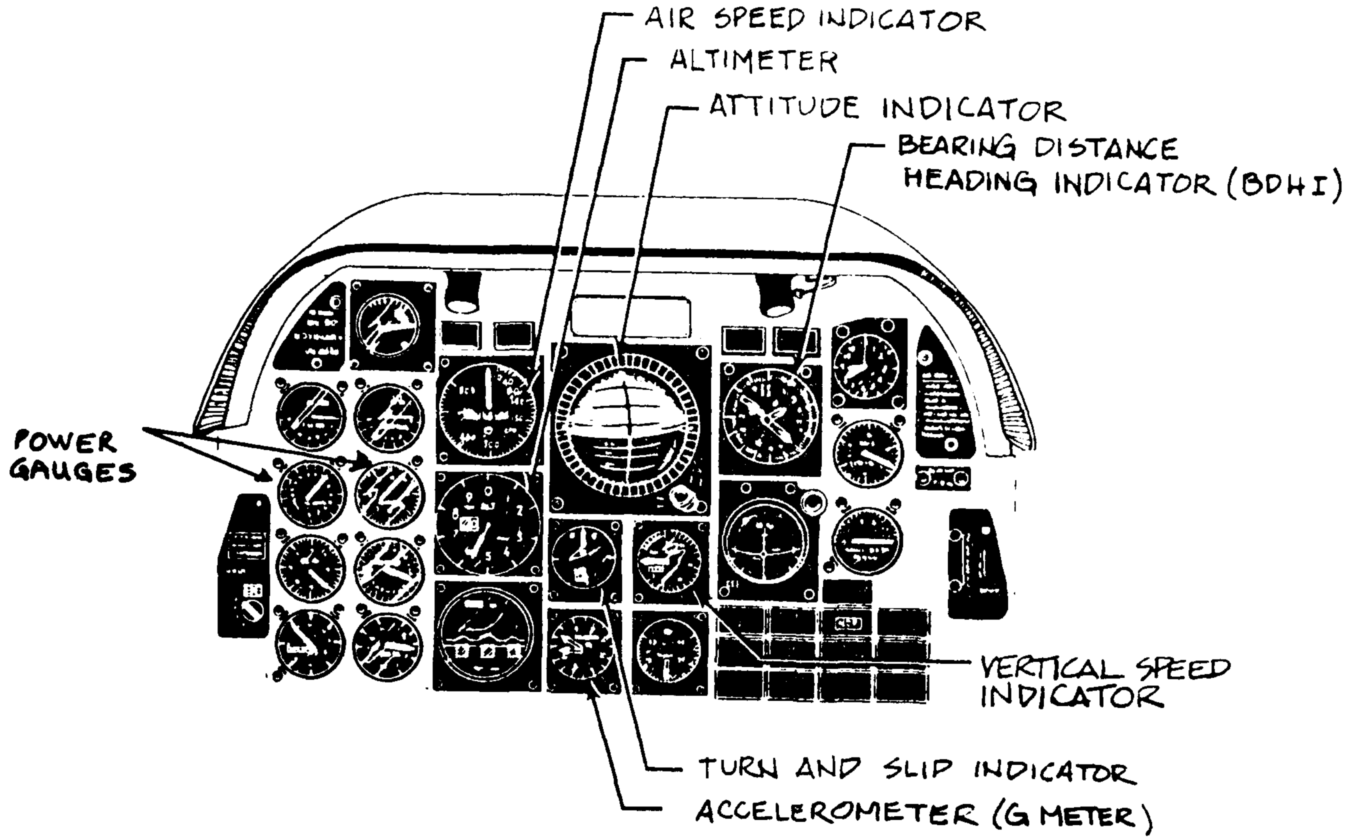

Table A8. Instrument Panel.

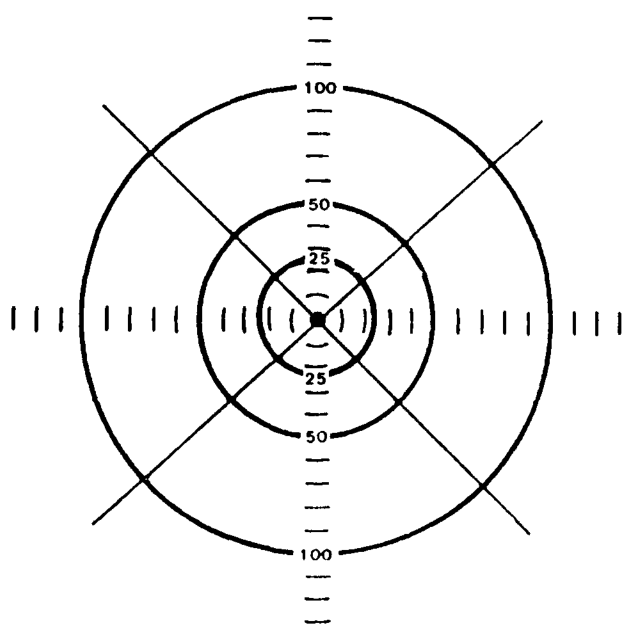

Table A9. The Gun Sight.

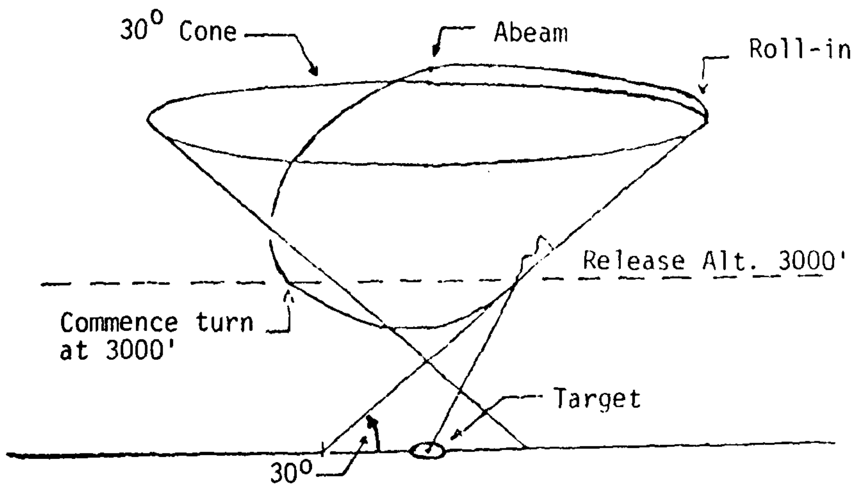

Figure A10. 30 Degree Cone Pattern-Side View

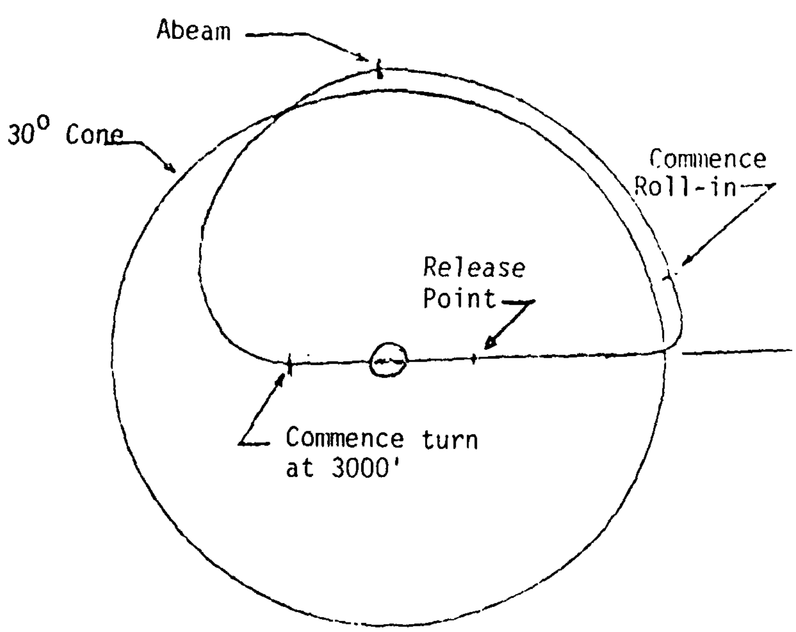

Figure A11. 30 Degree Cone Pattern-Top View

The task consists of:

1. flying a curved and level path towards the run-in line,
2. turning into the target approximately 30 degrees short of the run-in line,
3. rolling over to pull the nose down to a 30-degree dive as you close on the run-in line,
4. rolling out in a 30-degree dive and heading towards the target,
5. diving towards the target to release bombs at 3000 feet altitude, and
6. pulling out of the dive to establish a positive rate of climb.

You will be released from freeze in straight-and-level flight with an airspeed of 250 knots and altitude of 8000 feet and with the target abeam position about 1500 feet in front of you. Pitch trim will be set at -6.25 units (i.e., trimmed for the 30 degree dive) so that you will have to apply back pressure to the stick to maintain level flight. As you pass abeam the target roll into a 30 degree left bank to fly a circular pattern around the target. Maintain airspeed at 250 knots and altitude at 8000 feet.

At a point approximately 30 degrees short of the run-in line, roll into a 45 degree left bank. Apply more back pressure on the stick to maintain altitude. At a point approximately 10 degrees from the run-in line, roll to 120 degrees angle-of-bank and pull the 120 mil ring of the bombsight towards the target. Allow the nose to drop to 30 degrees below the horizon. As the bombsight nears the target, roll the wings level. You should then be in a 30 degree dive and on the run-in line.

If the approach dive parameters are not correct, take this opportunity to correct them insofar as is possible. You will be using the straight path tracking technique, so that the pipper of the bombsight should be tracking towards the target as you dive. The bombsight should drift over the target at a rate of approximately 30 mils for each 1000 feet of altitude loss. Thus if you need to adjust your bombsight placement after roll out, you should adjust it to be consistent with the altitude at the time of adjustment. At 4500 feet altitude (4950 indicated because of altimeter lag), which is 1500 feet above bomb release, the pipper should be displaced from the target by 45 mils. Adjustments in dive angle and bombsight placement should

be completed before you pass through 4500 feet altitude. Airspeed should be building towards 350 knots and should approximate 320 to 325 knots at 4500 feet altitude.

If, after your rollout, you find you are not lined up with the run-in line, simply accept the angling-in run (within 10 degrees) and correct your next roll-in. An effort to fly back to the run-in line is unnecessary, and wastes valuable tracking time.

After the aircraft passes through 4500 feet, hold a constant dive angle in balanced flight with wings level and with the aircraft accelerating towards release airspeed (350 knots). The pipper should track towards the aim point as the aircraft progresses in the dive. Under no wind conditions and assuming an ideal run, the pipper should be right on the target at the release altitude of 3000 feet (3450 indicated altitude). Careful attention to tracking and altitude is essential during this last few hundred feet of dive. Keep the altimeter in your scan and pickle the bomb at release altitude. Remember that the altimeter lags the true altitude by 450 feet during a 30 degree dive. Mentally adjust the altimeter reading by adding 450 feet to it at all times in the dive.

This final tracking phase is the most critical part of the weapons run. During the span of just a few seconds, you must not only control the motion of the pipper, but also continually cross-check your altitude, airspeed and dive angle. Figure A12 shows the relationship of the aircraft's line of flight to the sight angle and the flight path of the bomb after release. Note also the relationship of the line of sight during the run and at release.

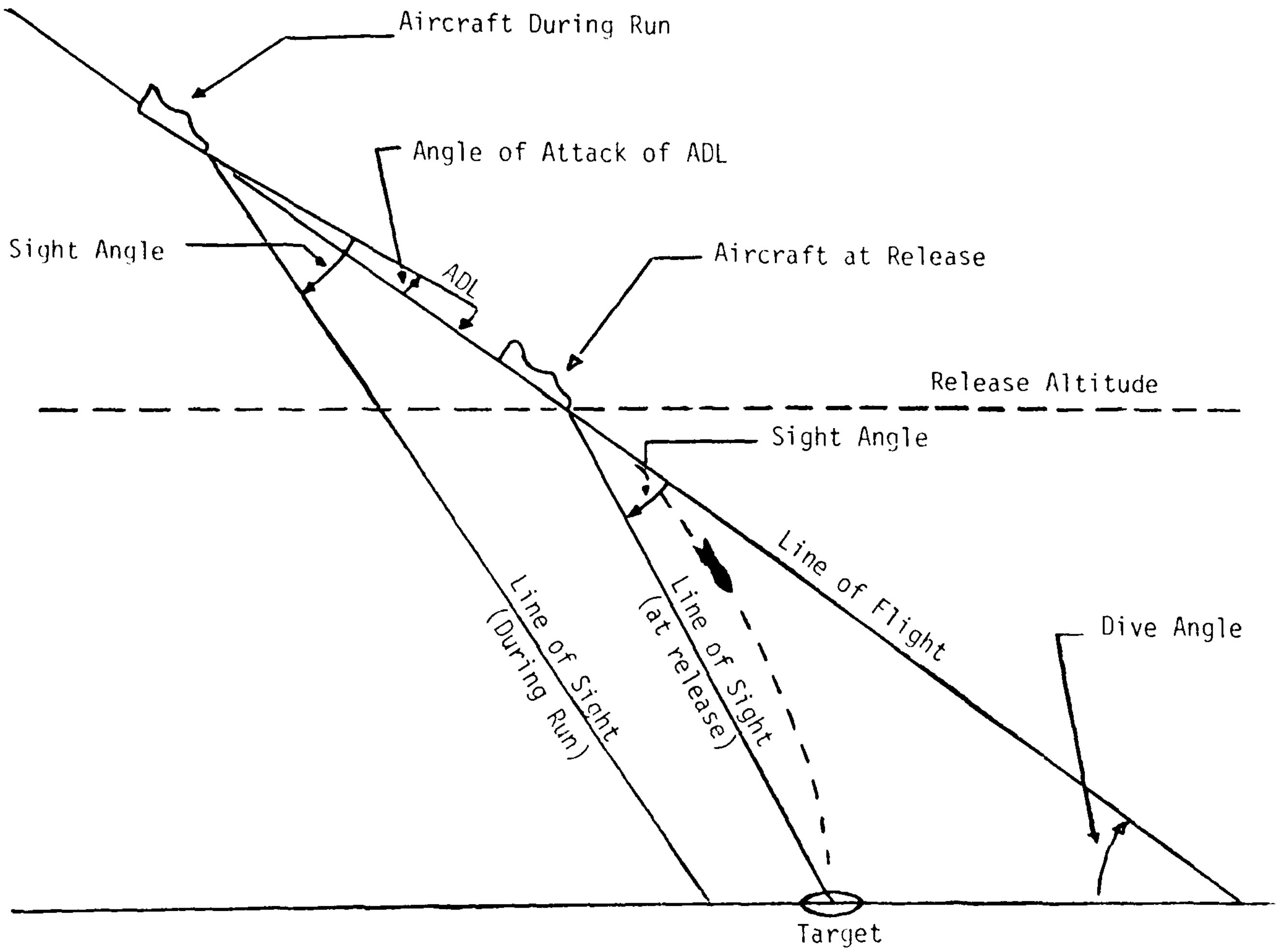

Figure A12. Profile of Bomb Pattern Sharing Line of Flight and Line of Sight Relationship

Pause a fraction of a second after bomb release (pickle-pause-pull), and then pull back on the stick to stop the descent and to establish a positive rate of climb. Monitor the accelerometer to ensure that loading does not exceed +4g. In a real aircraft structural damage could result. Do not use the trim button to ease pitch forces. You may overadjust and cause the aircraft to exceed the "g" limit. If you do not pull the stick back enough (shown by insufficient "g"), you will reach a lower than desired altitude during pullout (and possibly collide with the ground). The trial will finish 10 seconds after you release the bomb.

You will be advised of your bomb score in distance and clock coordinates at the end of each trial. Keep the following grades in mind to assess your own standard of performance.

Error	Grade
Less than 75'	Excellent
75' to 150'	Qualified
150' to 300'	Not Qualified
Greater than 300'	Off Target

ERROR CORRECTION.

There are two possible types of errors in ordnance delivery. Aircraft errors are induced by poor aircraft control. Atmospheric errors are produced by the action of wind force on the aircraft at the moment of weapon release. In this experiment you will need to consider only those errors resulting from poor aircraft control. These are the more difficult to correct because of time available for decisions once an error has been detected. In contrast, atmospheric conditions for the area of operation are generally known and the wind at release altitude can be forecast with reasonable accuracy, so that wind corrections can be calculated beforehand.

FACTORS AFFECTING TRAJECTORY

Airspeed - If you are fast, with all other parameters correct, the bomb will hit beyond the intended aim point, because gravity will have less time to act on the bomb and bend its trajectory down towards the target. Conversely, a slower airspeed will allow too much time for gravity to act and the bomb will fall short of the intended aim point.

Dive Angle - A shallower than desired dive angle will allow too much time for gravity to act on the bomb and will cause a short hit, assuming the pipper is on the target. Conversely, a steeper dive angle will cause a hit beyond the intended aim point because gravity does not have sufficient time to bend the bomb to the desired point on impact.

Altitude - A high release will allow gravity more time to act on the bomb and will produce a short hit. A low release will not allow gravity sufficient time to act on the bomb and will result in a long hit.

Other factors, such as "g" forces, bank and yaw, affect the flight of the bomb. A "g" loading of 0.87 is optimum and the aircraft should be in coordinated flight at the time of release to ensure the forces due to slipping or skidding do not affect the bomb trajectory.

BOMB BALLISTICS

When the bomb is released from the aircraft, it tends to parallel or fly along with the aircraft for a brief period. This is due in fact to the speed imparted to the bomb by the aircraft at release. As the bomb continues to fall, its flight path becomes more and more affected by gravity, which bends the bomb's trajectory towards the intended point of impact. The bomb never achieves a vertical flight path, although the bending effects of gravity on the latter portions of the bomb's flight steepen the path to nearly vertical (Figure A12).

The gravitational bending of the bomb's flight path requires that all of the delivery parameters are met--i.e., altitude, airspeed, dive angle, yaw, "g", etc. A predictable error will occur if all the parameters less one are met. Should more than one of the parameters not be met, the error is compounded and correction becomes more compex. There are numerous errors that affect the accuracy of the weapon drop. The most notable are release altitude, airspeed, dive angle and pipper placement. The errors produced by these factors will be explained along with simple correction techniques.

AIRCRAFT ERROR CORRECTION

For the purposes of the experiment, consider that a 30 degree pitch down on the attitude instrument will deliver a 30 degree angle and that 350 kts indicated airspeed is accurate. Remember that the altimeter lags by 450 feet in a 30 degree dive. Thus you must release at an indicated altitude of 3450 feet. The gunsight is preset to the appropriate depression angle.

Error Sensitivities - In order to make proper corrections, you must first know how much each error will affect your accuracy. The effects of changing the various parameters such as airspeed, altitude, and dive angle have been discussed in general terms. It was mentioned, for example, that a steep dive angle will cause a long hit, and that a high release will cause a short hit. So it is easy to see that a high release can be used to compensate for a steep dive angle. However, in order to actually make such a correction, you must know how high to release for each degree you are steep. In other words, for each type of run, you must know exactly how dive angle, airspeed and altitude affect accuracy, and how they relate to one another. The following table summarizes this information for a 30 degree bomb and should be memorized.

TABLE A-13. EFFECTS OF ERROR CONDITIONS AT BOMB RELEASE ON BOMB ACCURACY

	Dive Angle	Airspeed	Altitude
50 ft short	1 degree shallow	10 knots slow	100 ft high
50 ft long	1 degree steep	10 knots fast	

Also note that a 10 mil error on bombsight displacement represents about a 50 feet displacement of the pipper from the target at a release altitude of 3000 feet.

The error correction table will tend to permit satisfactory results only if parameters are within:

± 3 degrees for the dive angle,
± 30 knots for the airspeed, and
±400 feet for the release altitude

Thus your bombing runs must remain within these tolerances.

(a) Dive Angle Correction. If your dive angle is too steep as you approach release altitude, maintain your dive angle and adjust your release altitude accordingly. This is a simple correction to make if you know your error sensitivities. For example, if in a 30 degree bomb run you find that your attitude indicator is indicating 32 degrees as you approach release altitude, you can compensate by "pickling" 200 feet high. Another valid correction would be to release at normal altitude with the pipper 20 mils short of the final aim point.

To correct for a shallow dive angle, maintain that dive angle and change your aim point. For example, if in a 30 degree bomb run you find that your attitude indicator is indicating 28 degrees as you approach release altitude, you can compensate by pickling at normal altitude with the pipper 20 mils past the final aim point. You must be careful in making this correction, because pulling the pipper past the target can further shallow your dive angle and also increase the "g" load. However, if you have a shallow dive angle, the only correction you can make is to allow the pipper to drift long. Do not press the run below normal release altitude to correct for a dive parameter, or for any other reason.

(b) Corrections for Airspeed. Experience will help you anticipate large airspeed errors early in the run and to make appropriate power corrections. You must continually scan your airspeed during the dive to see that you will reach your computed release airspeed by release altitude. Last minute corrections for airspeed errors are similar to those used for dive angle errors. For example, if in a 30 degree bomb run you

find that you will be 20 knots fast at release, you can compensate either by pickling 200 feet high, or by pickling at normal altitude with the pipper 100 feet (20 mils) short of the target. If you are 20 knots slow, you can allow the pipper to drift 100 feet (20 mils) past the target by release altitude. Do not release below the normal release altitude to correct for a dive parameter, or for any other reason.

(c) Correction for Pipper Position. The position of your pipper at release is probably the most important single factor in determining where your weapon will hit. If you release with the proper airspeed, altitude, dive angle, etc., the weapon will impact where the pipper was positioned at release. Experience will help you to recognize early in the run that the pipper is not going to arrive at the proper final aim point by release altitude, and will help you to determine appropriate corrections. Sometimes an improper roll-in leads to improper pipper position. For example, if you roll in too far from the target, or allow the aircraft nose to drop in the initial portion of the roll-in, the pipper will not reach the target before you pass through the release altitude. Sometimes, however, even though you may have the proper dive angle and airspeed, you will find that the pipper is not where you want it to be as you approach your release point. The pipper may also reach the final aim point too early as a result of flying a cone pattern too close to the target.

If your pipper arrives at the final aim point before you reach the normal release altitude, you have an "early sight picture." If you pickle with the early sight picture (assuming proper airspeed, dive angle, etc.), your hit will be short because of your altitude error. On the other hand, if you pickle at normal release altitude, your hit will be long because the pipper will be past the target. If you try to hold the pipper on the target until release altitude, your dive angle will increase and you will release with insufficient G.

The proper correction is to notice the altitude at which you get your early sight picture, and to split the difference between that altitude and release altitude. For example, suppose that in a 30 degree bomb run, your pipper arrived at the final aim point of 3400 feet AGL. With proper airspeed, dive angle, etc., you could compensate by continuing to hold your 30 degree dive and pickling at 3200 feet AGL.

However, remember that improper pipper position can often be traced to an improper roll-in. If you find that you are consistently getting an early sight picture, and your dive angles are correct at release, then the problem may be that you are rolling in too close to the target or have too much nose-up trim.

In contrast to an early sight picture, a late sight picture cannot be corrected at release. If you reach release altitude and the pipper has not yet reached the desired aim point, you must either release at normal altitude or abort the run. Never release below normal release altitude to correct for a late sight picture, or for any other reason.

If you recognize during the run that you are going to have a late sight picture, correct with very slight back pressure on the stick to make the pipper track faster. You should be aware, however, that this technique will shallow your dive angle and may necessitate another correction.

In any case, you should try to analyze the reason for the late sight picture. It could have occurred because you rolled in too far from the target, or because you did not maintain altitude during the initial part of the roll-in, or because you pulled your nose down too far during the final part of the roll-in.

It is possible to have a pipper deflection offset to the right or left of the target. Although some corrections can be made for the error with forward firing ordnance such as rockets and guns, there is little or no last minute correction which would assist you with bombs, except recommend adjust pattern on next run. Therefore, the problem of pipper deflection will not be discussed.

(d) Corrections for Multiple Errors. In each of the foregoing discussions of error correction techniques, it was assumed that only one dive parameter was in error and that the rest was normal. For example, when we say that a 2 degrees error in dive angle will cause a 100 foot miss, we are assuming that the weapon is released at the proper airspeed and altitude, with the pipper on the proper final aim point. However, you will frequently find that more than one of your dive parameters is in error as you approach release. In such a case, the errors may be additive, or they may tend to cancel each other. For instance, suppose that in a 30 degree bomb run, you notice that your dive angle is 1 degree shallow and that your airspeed is 10 knots slow. If you have learned your error sensitivities properly, you will know that each of these errors will cause your hit to be 50 feet short, for a total of 100 feet, and that you could correct by allowing the pipper to drift 100 feet past the target by release altitude. On the other hand, if you happen to be 1 degree shallow and 10 knots fast, you will know that these errors will cancel each other and that no correction will be required. You can probably see, however, that trying to mentally compute corrections for multiple errors during the few seconds before release could become excessively complicated.

As you are aware by now, air-to-ground weapons delivery is not a simple learning task and you will be required to perform some outside preparation. In particular, we urge you to be very familiar with the aircraft's error sensitivity as presented in this section.

Should you have any questions concerning the pattern or any portion of the task, please do not hesitate to ask for an explanation.

We would like to thank you for your participation in this experiment.

APPENDIX B

LIST OF PERFORMANCE MEASURES COMPUTED ON-LINE FOR EACH TRIAL

Task Segments	Variables Measured in Each Segment	Summary Measures of Each Variable	
Cone-Roll	Air speed deviation (knots)	RMS	$= \frac{1}{n}\Sigma e_t^2)^{1/2}$
Roll-In	Lateral deviation (feet)	Bias	$= \bar{e}$
Roll-Over	Alt. Deviation (feet)	Variability	$= (\frac{1}{n}\Sigma e_t^2 - \bar{e}^2)^{1/2}$
Dive 5500-4500 ft	Roll (degrees)	where e	= error at time t
Dive 4500-3500 ft	Dive Angle Deviation (degrees)	n	= no. samples
Pull-Out	G-load (g-units)		
	Throttle position	AST*	$= \frac{r}{n}\Sigma \lvert P_t - P_{t-1} \rvert$
	Aileron Position	where	= stick pos.at time t
	Elevator position	r	= sampling rate=30 Hz
	Pedal position	n	= no. samples

Task Points	Variables Measured at Each Capture Point
Roll-in Max Roll Roll-in End Roll-over Max. Roll Roll-over End	Roll Angle Mag heading, Roll, Alt.
Dive 6000 feet Dive 4500 feet Dive 3000 feet Bomb Release	Aircraft x and y position, Roll, Airspeed Pitch, mag heading, Altitude G-load, Power
Bomb Impact	x distance from target y distance from target
Pull-out Max. G-load	G-load
Pull-out Min. Altitude	Altitude

*Average stick movement per second. This measure was only computed for stick variables. Other measures were not computed for stick variables.

APPENDIX B (cont'd)

LIST OF PERFORMANCE MEASURES
COMPUTED ON-LINE FOR EACH TRIAL

Definitions of Task Segments

Cone Roll	Start of task to completion of 60 degrees of turn or the point of roll angle greater than 45 degrees, whichever comes first. This should be about 45 degrees from the run-in line.
Roll-In	End of cone-roll to the point that roll exceeds 90 degrees.
Roll-Over	End of Roll-In to the point of roll angle back to within 10 degrees of level (after completing the roll-over maneuver).
Dive 5500-4500 ft	The dive from 5500 to 4500 ft of altitude.
Dive 4500-3500 ft	The dive from 4500 to 3500 ft of altitude.
Pullout	End of bomb release to termination of trial 10 seconds later.

NOTES

1. There were some technical problems with measures from the cone-roll, roll-in and roll-over segments. Consequently, they were not given much consideration in this report.

2. Not all summary measures make "sense" for all segments. These cases are generally obvious.

3. Altitude deviation was referenced to 8000 ft (Alt. deviation = Alt.- 8000) through the roll-in segment. For the dive, the reference altitude was computed as the point on the 30 degree cone at the ground distance of the aircraft from the target.

4. Airspeed deviation was referenced at 250 knots through the roll-in segment. For the dive the reference airspeed was linearly interpolated between 250 and 350 knots for altitude between 8000 and 3000 feet. The latter method is not considered "perfect" and measures involving this computation were not given much weight in the report.

5. Dive angle deviation was referenced to 30 degrees for the dive segments.

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